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INDEPENDENT METHOD FOR THE IDENTIFICATION OF DRIVING TRAIN AS AN ALTERNATIVE TO CRITICAL RAIL INFRASTRUCTURE MONITORING

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Abstract – The article presents a novel, independent method for recognizing the type of moving rail vehicle as an alternative to current solutions. The procedure for the implementation of the developed method consists of the following stages: registration of vibroacoustic signals, normalization of signals, preliminary statistical analysis, selection of WT analysis wavelets, MODWT analysis, completion of a database with information on the relative energy of the signal, compilation of results and determination of features distinguishing rail vehicles in terms of the information capacity of the vibroacoustic signal, final classification of the type of vehicle.

Key words – identification, transport, vibroacoustic.

INTRODUCTION

The topic of an independent method for the recognition of driving train is important for the operational safety of railway critical infrastructure. Nowadays, more and more importance is being attached to the development of new methods, especially those that prevent accidents in transport. In this context, the identification of vehicles using vibroacoustic signals is becoming increasingly desirable due to its potential in the field of rail traffic and its monitoring principles.

The identification of rail vehicles in the context of an independent method from existing ones is a scientific challenge. Existing methods for vehicle identification are limited to specific situations and have many disadvantages, such as computational complexity or the high price of measurement equipment or the need for complex classifiers. At the same time, the topic has application potential, and its development can bring several benefits in many areas, such as road and rail route safety, traffic monitoring or the optimisation of transport processes. With the development of technology, vehicle identification based on vibroacoustic signals is becoming increasingly feasible and practical.

1. RESEARCH PROBLEM

Rail vehicle identification is a technical issue that requires a thorough understanding of the specific operation and characteristics of rolling stock and the technologies used [11-12]. This identification is important for the safety and efficiency of rail transport operations, as well as for ensuring proper maintenance of the rail infrastructure [1-2].

Compared to the identification of road vehicles, the issues of identifying rail vehicles are not as thoroughly studied. Understanding how they work requires specialised and extensive knowledge, for example of the specifics of signalling and traffic control systems, as well as the complex diagnostic systems used on rail vehicles [3-4].

In addition, rail vehicle identification takes place under conditions with different characteristics from those of road vehicle identification and requires a different approach to the issue [5]. For example, rail vehicle identification systems must operate under HSR (High Speed Rail) conditions, i.e., above 250 km/h (according to UIC-Union Internationale des Chemins). The rail vehicle identification systems used in Poland can be divided according to their nature and purpose of installation in the railway gauge area. In recent years, the technology of systems based on intelligent mechanisms (ITS - Intelligent Transport Systems and IIS - Intelligent Infrastructure System) has been significantly developed. These mechanisms, which have been used extensively in road transport also in Poland in the last decade, are slowly becoming successful in the railway area as well. They may help to solve problems of system integration, unification, and standardisation in the future. Thanks to numerous modernisations and infrastructure expansions, modern rail vehicle identification solutions are being used more and more frequently. An additional incentive for modernisation is the public's desire for increased safety, reliability, punctuality and efficient use of infrastructure.

The use of modern elements of railway infrastructure management issues that the role of man in control and management of transport is diminishing [6]. Centralised units, such as area-based railway control centres, are increasingly emerging. There has been a noticeable increase in interest in the implementation of automatic advisory systems, developed according to pre-established operating algorithms [7-8].

A very important aspect from the point of view of rolling stock management is the acquisition and exchange of necessary information in the process of optimising transport processes. The time it takes for the information to reach the recipient and be processed and analysed is important. [9, 10] The emergence of vehicle identification systems is also important for passenger information systems. Increasingly, detailed information is required about the location, sequence of trains on the railway line, number, and type of carriages and, for example, the location of doors in carriages as part of the rolling stock. The systems currently used on the PKP PLK S.A. network do not allow efficient identification of individual train sets, which may result in erroneous messages for passengers under certain unfavourable conditions.

2. RESEARCH METHOD

The proposed research method consists of recording vibration signals of the rail in three orthogonal axes and synchronous measurement of sound pressure. In the signal processing stage, a preliminary analysis of global statistical measures and a wavelet analysis based on the Maximal

Overlap Discrete Wavelet Transform (MODWT) were applied. After selecting the appropriate wavelet and performing the MODWT analysis, the relative energy measures of the signals were determined by predefined decomposition levels (details and approximations).

After performing the necessary analyses and determining the relative energy levels in the predefined decomposition levels, the proposed levels identifying the characteristic components were determined These were presented as percentages and are referred to as conditions in the following section. They were determined from the results of the analyses separately for the coif and fk wavelets.

In order to facilitate the reading of the given conditions, a unified colour system was used, as shown below.

Table 1. Colour coding used in the work.

Colour coding used in the work			
Passengers Train (P)	Locomotive/ Single Train (L)	Freight depot (T)	Electric multiple unit (E)

The proposed conditions (1, 2 or 3) for the four categories of train depots analysed are presented below.

Based on the analysis (coif wavelet), the following number of terms has been established:

- for P-type trainsets: 3 conditions (X-axis level 5 >25%; Y-axis level 5 >25%; sound pressure level 4 >20%),
- for L formations: 3 conditions (X axis level 4 >50%; Y axis level 3 >20%; Z axis level 4 >40%),
- for T formations: 2 conditions (Z axis level 6 >10%; Z axis level 7 >1%),
- for E-type compositions: 1 condition (Z-axis level 3 >20%).
- Based on the analysis (wavelet of the fejer-korokvin type), the following number of conditions was determined:
- for P-type compositions: 3 conditions (X-axis level 5 >20%; Y-axis level 5 >15%; sound pressure level 4 >20%),
- for L formations: 3 conditions (X axis level 4 >35%; Y axis level 3 >30%; Z axis level 4 >35%),
- T formations: 2 conditions (Z axis level 7 >2%; sound pressure level 6 >25%), E formations: 1 condition (Z axis level 3 >15%).

The proposed summary is the result of an analysis of the results of the average-with rejection of the extreme 10% summary of the compositions for the vibroacoustic signal. It is a proposal to categorise train compositions based on characteristic values of relative energy contained in the given decomposition level scales by the MODWT method.

The proposed algorithm should be analysed starting from formations containing the most conditions to be fulfilled, ending with those having the least. When classifying a depot, the following sequence should be followed:

- classify first to depots meeting three conditions, i.e., P or L.,
- if the depot has not fulfilled the three conditions, proceed to attempt to classify the depot for category T with two conditions,
- if the above conditions are not met, proceed to Category E, where the classified signal must meet one condition,

- when the signal under consideration does not meet all the conditions or meets them in several categories, adopt the principle of prioritising formations first with three, then with two conditions,
- when the signal under analysis has fulfilled three or two conditions for P, L or T depots, it shall not be analysed for the case of category E.

The concept of the MODWT analysis rail vehicle identification algorithm is as follows:

- Registration of noise and vibration accelerations of the rail in three axes.
- Selection of the analysis window. The analysis window is a fragment of signals verifying the passage of a rail vehicle.
- selection of wavelet fk or coif (no. 4 of level 8). Possible options are fk wavelet (feyer-korokvin) or coif wavelet (coiflet).
- MODWT signal processing. This transformation allows the signal to be analysed at different frequency scales.
- Analysis of relative energy values.
- Comparison of results to predefined conditions. Comparison of the readout relative energy values with the predetermined conditions.
- Preserving the order in which types of compositions are determined starting with those with the most conditions- the algorithm takes into account the order in which types of compositions are determined starting with those that have the most conditions. This makes it possible to assign the train set to the appropriate group more precisely and efficiently.
- Classification of the trainset into one of the predetermined groups (L, P, T or E).
- The proposed concept of a method for identifying railway vehicles based on MODWT analysis makes it possible to classify types of depots based on the relative energy of the vibroacoustic signal.

3. Results

The research carried out made it possible to develop a complete method for solving the issue addressed in this article.

The developed method makes it possible to initially identify the type of rail vehicle and determine the characteristic features of the vibroacoustic signal. It can be used to support the identification of vehicles by the vibroacoustic method, as well as for the analysis of different types of vehicles. The current state of research allows classification into the following groups of rail vehicles: passenger trains (P), goods trains (T), electric multiple units (E) and locomotives/trucks running 'solo' (L).

The vibroacoustic signals contain information components that enable the identification and classification of the moving rail vehicle. This information was obtained by creating a database containing the characteristic features of the vibration and acoustic signals. Synchronous recording of vibration and acoustic signals expands the amount of useful information to support the classification process.

Due to the significant application potential of the developed method for rail vehicle identification, additional validation tests were carried out. For this purpose, analytical experiments were carried out with 10 selected randomly recorded signals of moving railway trainsets.

The same trainset signals, labelled ew10, tw2, tw4, T4, o21a, o18a, o20a, lw3, pw6, ew9, were used in both tests with selected fk and coif waveforms.

Table 2 Colour coding used in the work

Categories	Term 1	Term 2	Term 3
L	Exists	Exists	Exists
P	Exists	Exists	Exists
T	Exists	Exists	Does not exist
E	Exists	Does not exist	Does not exist

The MODWT was then analysed according to the guidelines proposed in the rail vehicle identification method concept. The relative energy values were read out and the results were compared to the predefined conditions.

The validation results for the coif wavelet are as follows:

- For the coif wavelet correctly qualified depots; ew10, tw2, tw4, T4, o21a, o18a, o20a, lw3. (8 out of 10 depots). - table 3.

- For the coif waveform qualified erroneous line-ups: pw6, ew9 (2 out of 10 line-ups) - Table 4.

These results are shown in Table 3, where green indicates compliant line-ups and red indicates line-ups that did not meet all conditions or were duplicated (for category E).

Table 3 Classification results of 10 randomly selected compositions classified into selected category types for the coif wave

Categories	Term 1				Term 2							Term 3				
E	tw2	tw4	ew10	pw6												
T	tw2	tw4	pw6	T4	T4	tw2	tw4	ew10	o21a	pw6						
P	o21a	o18a	pw6	o20a	o21a	o18a	o20a					ew9	o21a	o18a	pw6	o20a
L	T4	ew9	lw3		T4	Tw2	Tw4	ew10	Ew9	lw3	pw6	ew9	lw3	o21a		

Tabela 4 Compositions misclassified but meeting conditions-wave coif.

Categories	Term 1				Term 2							Term 3				
E																
T			pw6							pw6						
P																
L		ew9							ew9			ew9				

The validation results for the fk wavelet are as follows:

- For the fk wavelet correctly classified depots: ew10, tw2, tw4, o20a, o21a, o18a, lw3 (7 out of 10 depots). - Table 5
- For wave type fk misqualified depots: T4, pw6, ew9 (3 out of 10 line-ups) (Table 6).
- For fk wave type double qualified line-ups: T4.

These results are shown in Table 6, where green indicates the compositions that met the conditions and red indicates the compositions that did not meet all the conditions or were duplicated (for category E).

Table 5. Classification results of 10 randomly selected compositions classified into selected category types for wave fk.

Categories	Term 1					Term 2					Term 3		
E	tw2	tw4	ew10	o21a	pw6								
T	T4	tw2	tw4	o21a	pw6	T4	tw2	tw4	ew9	pw6			
P	o20a	o21a	pw6	o18a		o20a	o21a	o18a			o20 a	o21a	o18a
L	T4	ew9	lw3			T4	ew9	lw3			T4	ew9	lw3

Table 6. Misclassified but compliant compositions - fk wave.

Categories	Term 1					Term 2					Term 3		
E													
T	T4				pw6	T4				pw6			
P													
L	T4	ew9				T4	ew9				T4	ew9	

The correctness of the use of the coif wavelet is 80% on a sample of 10 compositions, while it is 70% for the fk wavelet. During the validation of the method, the identification performance was assessed using two different wavelets: coif and fk. The results obtained from the analysis of 10 different train sets showed that the classification efficiency when using the coif wavelet was 80%, while that of the fk wavelet was 70%. This confirms the application potential of the developed rail vehicle identification method. Conducting additional validation tests made it possible to assess and confirm the effectiveness of the developed identification method. Further research and refinement of the method can yield even better results and provide a solid basis for the practical application of the method in rail vehicle identification.

4. SUMMARY

A method of identifying the type of a passing rail vehicle using vibration and acoustic signals has been developed by creating a proprietary unique system for categorising depots using MODWT analysis and using scale information in the Relative Energy of the vibroacoustic signal.

It is possible to identify the type of passing rail vehicle from the analysis of vibroacoustic signal images through the proposed rail vehicle identification algorithm. Its efficiency in the case of COIF waveform selection is about 80% while that of FK waveform is about 70%.

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