SIGNAL COMPRESSION IN AUTOMATIC ULTRASONIC TESTING OF RAILS

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Summary Full recording of the most important information carried by the ultrasonic signals allows realizing statistical analysis of measurement data. Statistical analysis of the results gathered during automatic ultrasonic tests gives data which lead, together with use of features of measuring method, differential lossy coding and traditional method of lossless data compression (Huffman's coding, dictionary coding), to a comprehensive, efficient data compression algorithm. The subject of the article is to present the algorithm and the benefits got by using it in comparison to alternative compression methods. Storage of large amount of data allows to create an electronic catalogue of ultrasonic defects. If it is created, the future qualification system training in the new solutions of the automat for test in rails will be possible.

1. INTRODUCTION

The need of automation of ultrasonic testing of rails is obvious, because of the fact that the manually driven measurement do not guarantee enough efficiency and quality and its cost is much higher then the cost of automatic testing. Besides if we consider the specifications of train speed and the intensity of traffic, good knowledge of what condition the rail surface is in and the ability to make good decisions on the basis of the relevant information is becoming an essential condition to keep safety [1].

The analysis of the solutions of the automata for ultrasonic tests used nowadays [1, 2] shows that the main problems that the system developers struggle with are providing with the right speed of processing the large data stream and the acquiring the huge amount of measurements.

One of the possible solutions for both problems can be an algorithm that is fast (the possibility to compress data while gathering) and efficient (assuring the high level of compression) enough to cope with compression of the measurement results that come from automatic ultrasonic tests.

2. DATA ACQUISITION IN AUTOMATIC ULTRASONIC MEASUREMENT

When we analyze basic test methods that are being used in ultrasonic tests, we can observe, that the most important information used to analyze the ultrasonic signal is included in a few parameters describing the characteristic points of the picture of ultrasonic echo on the testing car screen. The most basic parameters are maximum amplitude of defect echo (the biggest amplitude of the signal in the test monitor that determine observation area), defect echo location, maximum amplitude of bottom echo (in bottom monitor) and the bottom echo location. The parameters are presented in figure 1.

The measurement results in automatic tests are most often supplied with the information about dimensional placement of the tested cross-section and changeable parameters of testing equipment.

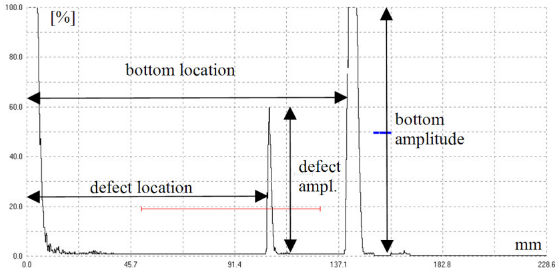


Fig. 1. Characteristic parameters of the ultrasonic echo picture

When the characteristic parameters of ultrasonic test in function of scanner placement Δx are plotted, it is easy to get an envelope chart (Fig. 2).

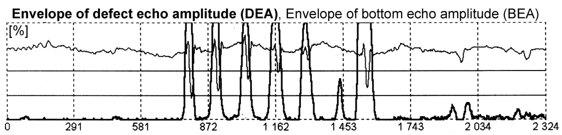


Fig. 2. Characteristic parameters of the ultrasonic echo picture

The shape of envelope is connected to both dimensional defect geometry and geometry of the probe beam. For small defects (that is much less than the size of wave beam) the envelope length cannot be the measure of defect extent. However for large defects there is an advantageous correlation between the size of echo in the envelope and the defect size.

The measurement results gathered according to the methodology presented will be the basis of further deliberation and suggested solutions. The suggested modification leads to so significant signal transformation that its character changes, but the measurement signals acquired this way still contain the essential information that is necessary in the process of analysis of the defects.

The suggested algorithm describing data acquisition of the results leads both to limitation of the gathered data (compression factor in the measurements on the research stand reached the values k > 0,9988 – compression higher than 1:750; $k = \frac{N_{IN} - N_{OUT}}{N_{IN}}$, where N_{IN} – the size of input data, N_{OUT} – the size of output data after the compression), but it also assures the visualization of the registered defects, which is very convenient for the operator (fig. 2) and it is suitable for equipment implementation in automats used for ultrasonic testing.

3. COMPRESSION OF ENVELOPE SIGNALS

The multistage algorithm of measurement compression is presented to find an effective solution to the problem of measurement acquisition in automatic ultrasonic testing of rails. The scheme of it is presented in fig. 3. Its effectiveness was verified by gathering the measurements on the test rail with artificial defects in Warszawa Odolany.

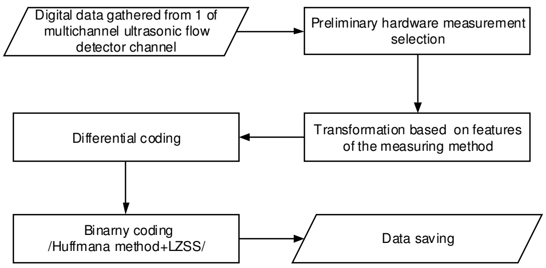


Fig. 3. General scheme of the algorithm of result compression gathered in automatic ultrasonic tests.

The compression of the measurements starts already when they are gathered – the first stage of coding is preliminary filtration of measurements – the system registers their results only for these scanner placements, where at least one of the registration criteria are granted. It can for example be when the defect echo amplitude exceeds the set level.

The second stage of coding is removing the redundancies connected with measurement method features. On that stage we delete the data that are being processed not because of the measurement needs, but because of measurement technique features or automat construction (coding of defect placement in many channels, lack of bottom echo for angle probes, processing the same signal in two channels with different gains).

The next stage is to use the differential compression method [3, 4]. The idea of using differential coding came to the authors with statistical analysis of measurement results gathered during the rail tests. Its partial results for the ultrasonic probe with the angle of wave 72° is presented on histograms (fig. 4).

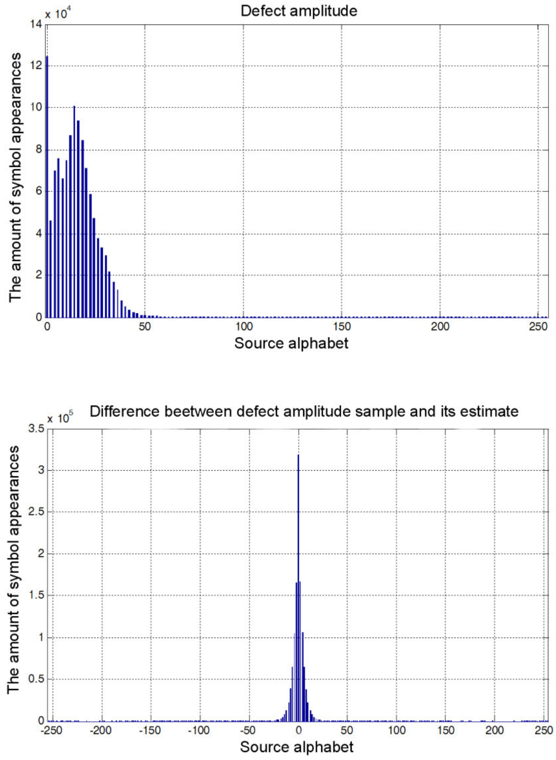


Fig. 4. Histograms of defect amplitude envelope and differences between their samples and sample estimates during the measurement with echo measurement method in the channel that uses angle probes β = 72°.

The basic idea of differential coding consists in replacing the source data $\{x_n\}$ with the sequence $\{d_n = x_n - x_{n-1}\}$. Such transformation gives effective coding results only when the sequence variation $\{d_n\}$ is significantly less than source data variation (strong correlation). In [4] it is proved that for the lossy compression to avoid the problem with error cumulating during the reconstruction it is necessary to replace the previous sample value x_{n-1} with the value of its reconstruction $\hat{x}_{n-1}$ during the forming of the sequence $\{d_n\}$. The operation of computing differences need to be modified $d_n = x_n - \hat{x}_{n-1}$.

The procedure motioned above leads to a complete reduction of the total quantization error for the constant number of bytes per sample or if we do not want to reduce the error we can get the same distortion by less number of bytes per sample.

The advantages of differential coding are also comparatively simple algorithms that use the signal features and the high processing speed, that comes from their relative simplicity, and relatively small demand for computer recourses.

One of the goals of differential coding presented in fig. 5 in block form is decreasing the variation σ_x^2 of coded signal and making it more susceptible to coding by the reduction of the amount of code symbols in source alphabet.

In the further stages of processing lossy data compression and lossless data compression with the variable-length codes are used. So the important effect of the transformation is a change of probability of code symbols appearing that they become even more skewed (fig. 4).

Large skewness of the probability conduces both the lossy compression (if we eliminate the symbols with least probability from the code, the distortions will be slightest) and the statistical modeling algorithms – we use shorter codes to more common symbols.

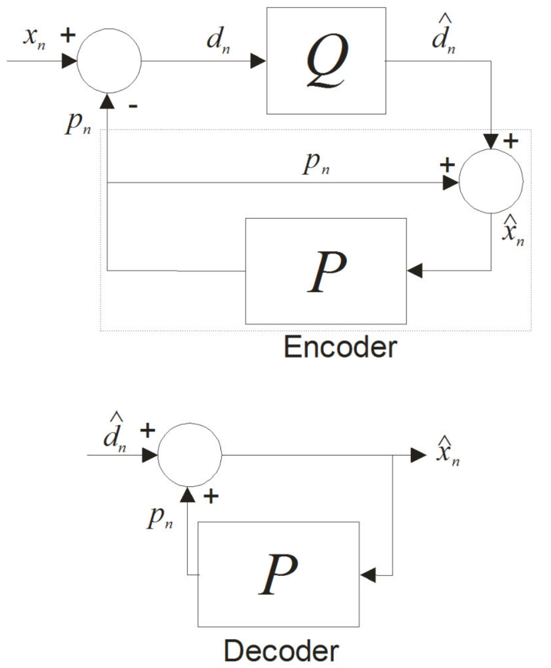
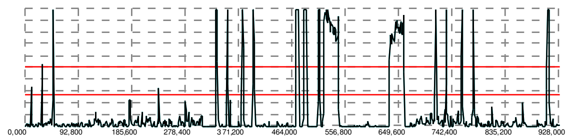


Fig. 5. Basic algorithm of differential coding system with the use of predictor

Reduction of symbol amount in source alphabet leads to the reduction of size of gathered data (to code less amount of symbols shorter code words are sufficient). The cost of the lossy transformation is real reduction of measurement resolution, but as mentioned before, elimination of the least common symbols from the alphabet when the favourable statistical features occur (fig. 5) brings in small distortions (shown in fig. 6).

Lossless compression (the last stage of algorithm) is possible thanks to redundancy in information in input data and some different dependences occurring in the structure of coded values sequences [4]. The gist of lossless coding is a such way of describing source data, that the output data use less space but still keep the possibility of synonymous decoding. The best results if we consider the analyzed problem were obtained by using cascade connection of the dynamic version of Huffman's coding and dictionary coding method LZSS [3, 4, 5, 6]. The tests were made for original courses (without differential transformation) and transformed with differential coding. In the test both dictionary method version LZSS, dynamic Huffman's method and the combination of both methods were taken into consideration.

a) $A^{(8)}$ alphabet size of 256 symbols



b) $A^{(5)}$ alphabet size of 32 symbols

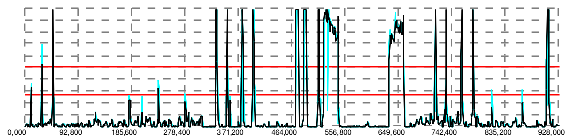


Fig. 6. Original and reconstructed signals of defect amplitude envelope depending on the size of code alphabet – normal probe

The results for the measurements with probes with the angle of wave 0°and 72° were compared with the results for the same data gathered by commercial archive programs (fig. 7 and 8). Particular groups on the graphs (DEA – defect echo amplitude, DEL– defect echo location, BEA – bottom echo amplitude, BEL – bottom echo location) show the results gathered during the compression of one type of envelope.

4. CONCLUSION

The anticipated effect of the data redundancy reduction was going to assure the possibility of gathering measurements from ultrasonic test of one or more railway tracks, so that the operator after finishing the measurements was able to go through the defect images and was able to verify the automatic qualification results suggested by the system. The results from the developed conception are better then expected. After compression data size is reduced so much that it allows to gather and keep the measurement results for long time.

Such a big reduction of data redundancy was obtained among other thanks to the analysis of measurement gathering process, statistical processing of gathered results and then using the knowledge about the structure of gathered data in the process of creating the coding algorithm by the authors.

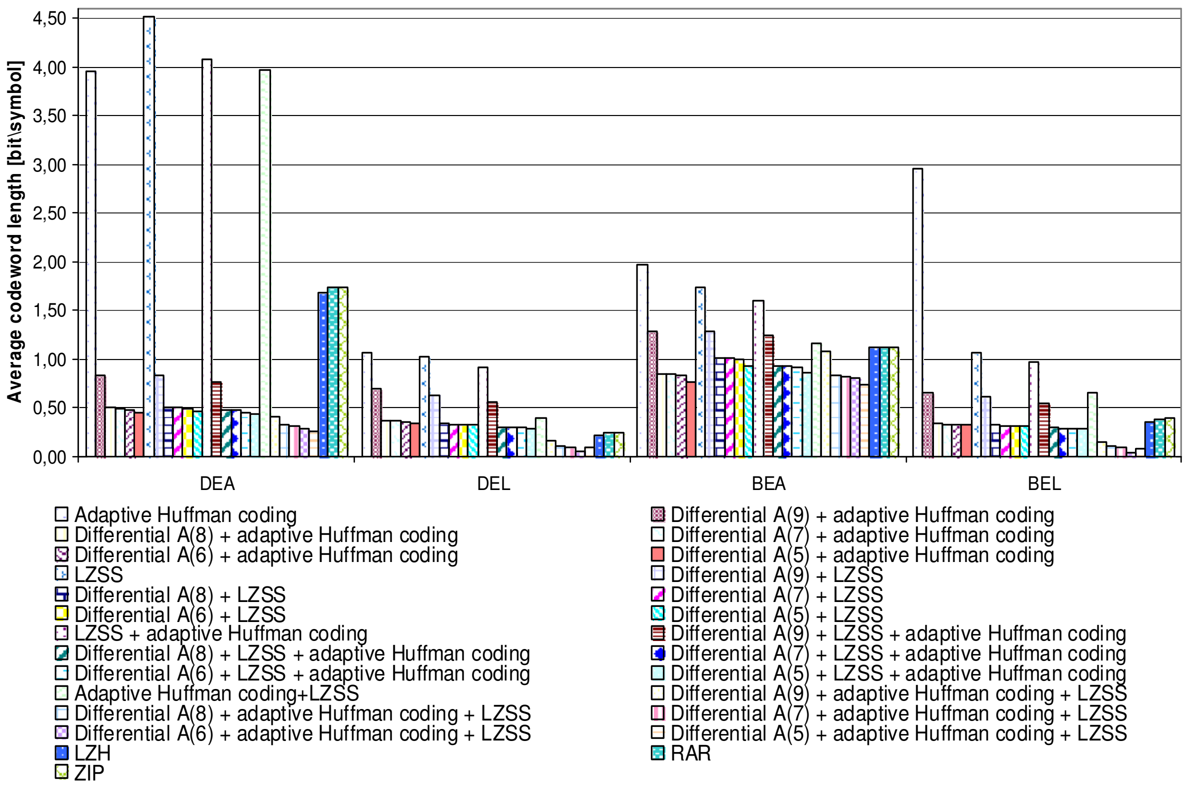


Fig. 7. Effects of binary coding for the signals from automatic ultrasonic measurements with echo method and normal probes – 0°

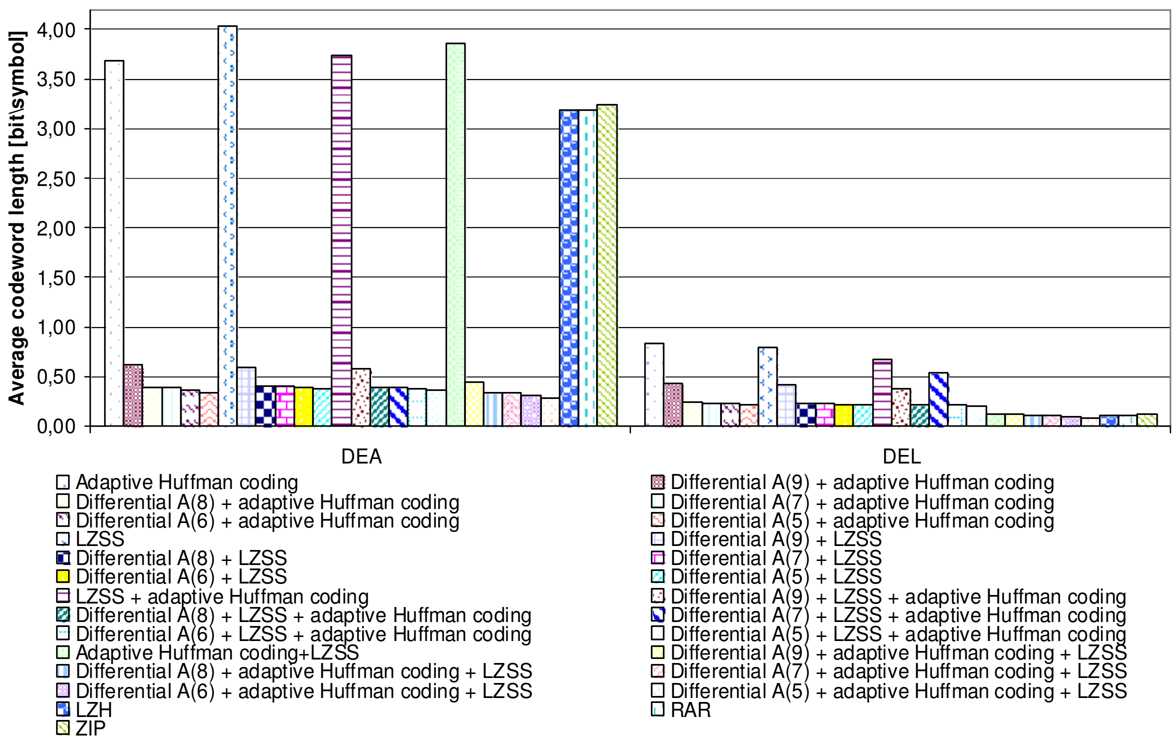


Fig. 8. Effects of binary coding for the signals from automatic ultrasonic measurements with echo method and angle probes – 72°

The other possibility of long-lasting storage of data that opens the new class of research. Especially the new perspective of processing comparison method of analysis, where during the tests the results of next rail inspection will be compared. It gives a possibility to eliminate some fake defects (they should not be discovered during the next measurements) and following the proves of defect grow (in case they are not classified as dangerous).

As a result of the current exploitation of measurement equipment an electronic catalogue of ultrasonic defects could be created. If it is created, the future qualification system training in the new solutions of the automat for test in rails will be possible.

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