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COMPARATIVE ANALYSIS OF A CODEC WITH ADAPTIVE DIFFERENCE QUANTIZATION (ADQ) FOR COMPRESSION OF MEASUREMENT SIGNALS

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Abstract - The paper presents an analysis of a coder with adaptive difference quantization (ADQ) [1] for compression of measurement signals. Thanks to the adaptation of the compression algorithm parameters to the variability characteristics (i.e. to the dynamics) of the signals recorded, the compression ratio can be optimised. The results of the study on efficiency (compression ratio) of the discussed compression algorithm compared with known lossless algorithms are presented in the paper. The study was carried out taking into account the influence of dynamical properties of the measurement signals.

Keywords: signal compression, compression algorithm, adaptive compression

1. INTRODUCTION

The measurement signal compression of a physical quality can result in a substantial reduction of the amount of the information memorised; and the signal compression before quantization can be one of the methods. The problem of signal compression before quantization is known in the field of sound signal transmission [2], where the emphasising of weak signals with the simultaneous compression of strong signals enables a constant relative quantization error to be obtained. The operation of the above-mentioned algorithms consists in the one-to-one inertialess and nonlinear processing operations where logarithmic functions are used. The application of these algorithms to compression in the continuous measurement signal logging process does not produces the expected results.

The authors analyse in the paper another version of the inertialess and lossless adaptive difference quantization (ADQ) algorithm [1] for the compression which leads to a reduction in the absolute and relative quantization errors both for weak and strong signals at the unchanged quantizator resolution (the processing accuracy improvement effect). In other words, which - at the reduced quantizator resolution - allows for the preservation of the assumed input quantization error (the effect of the registered measurement data lossless compression). Although the algorithm itself is inertialess, its efficiency depends on the dynamics of the measurement signal undergoing compression. Thanks to the adaptation of the compression algorithm parameters to the variability characteristics (i.e. to the dynamics) of the signals recorded, the compression ratio can be optimised.

2. ADQ COMPRESSION ALGORITHM

The compression algorithm with adaptive difference quantization (ADQ) [1] consists in the inertialess, lossless and nonlinear conversion of the measured signal $u(t)$ before the quantization. This conversion can be carried out in an analogue or digital way to the measured signal $u(n)$ sampled and quantized with much higher resolution according to the following coder function:

$$u_1(n) = \left(u(n) - u(n-1)\right)\cdot m(n) \qquad for \quad n = 1,2\ldots \qquad (1)$$

and
$$u_1(0) = u(0) \qquad for \quad n = 0 \qquad (2)$$

where the multiplier $m(n)$ is expressed as:

$$m(n) = 2^{M(n)} \qquad for \quad n = 0,1,2\ldots \qquad (3)$$

and $M(n)$ is an integer defined as:

$$\left.\begin{array}{ll} M(n) = \left\lfloor \log_2 \dfrac{U_z}{|u(n)-u(n-1)|} \right\rfloor & for \quad n = 1,2\ldots \\ M(0) = \left\lfloor \log_2 \dfrac{U_z}{|u(0)|} \right\rfloor & for \quad n = 0 \end{array}\right\} \qquad (4)$$

and meeting an additional constraint:

$$0 \le M(n) \le N - 1 \qquad (5)$$

where: U_z – measuring range of the signal $u(n)$ recording system.
The number N of bits results directly from the assumed limiting quantization error $2\cdot\delta_q=1/2^N$ with which the measured signal $u(n)$ is recorded.

The compression algorithm works as follows [1]. For a specified sample of the signal $u(n)$, a difference is determined between its value and the sample value just before (relationships (1) and (2)). The difference is then multiplied by the coefficient $m(n)$ which is determined according to equations (3) through (5). It is easy to see that the value of

$m(n)$ depends on the signal dynamics: the larger the difference between the values of the successive samples, the smaller is the value of the multiplier $m(n)$. This results from the fact that the signal $u_1(n)$ obtained from such a conversions has to be contained within the given measuring range U_z. It should be noted that the multiplier $M(n)$ determined according to (4) for a very small (even almost zero) difference between the values of the successive samples will assume a large value exceeding considerably N. The limitation (5) is therefore necessary from the operation correctness and compression algorithm efficiency point of view.

The $m(n)$-fold signal difference amplification causes that the quantization error will be reduced $m(n)$ times if the quantizator of unchanged resolution is applied in the further part of the channel (or, in other words: a quantizator of resolution smaller by $M(n)$ bits may be applied, which will result in the decrease by $M(n)$ of the number of bits necessary for recording values of the signal $u(n)$ while the unchanged quantization error of the compressing system compared to the non-compressing system).

After being sampled, the measured signal u(n) is compressed following the relationships (1) through (5) and the resulting signal $u_1(n)$ is quantized in a (N-$M(n)$)-bit quantizator. We get this way the compressed signal $u_q(n)$. Based on (5), we now see that for the limit number $M(n)=N$ - 1 bits we get a 1-bit quantizator.

Signal reproduction requires using a decoding procedure according to the decoder function:

$$\left.\begin{aligned} u_d(0) &= \frac{u_q(0)}{m(0)} && \textit{for} \quad n=0 \\ u_d(n) &= u_d(n-1)+\frac{u_q(n)}{m(n)} && \textit{for} \quad n=1,2\ldots \end{aligned}\right\} \tag{6}$$

where: $u_q(n)$ – signal $u_1(n)$ quantized in a (N-$M(n)$)-bit quantizator

$u_d(n)$ – signal obtained after decoding.

As was mentioned before, the adaptation of the compression parameter $M(n)$ to the variability characteristics of the recorded signals was used, which results in an automatic optimisation of the compression ratio. The differences between the successive samples are small for constant or slow-changing values of the signal $u(n)$; they increase with signal frequency. As can be seen in (4), the optimum compression parameter $M(n)$ is selected depending on a value of the difference.

The signal $u_q(n)$ quantized in $(N\text{-}M(n))$ bits quantizator is coded using the varying length code (with prefix property), which is binary recorded to the file as a stream of bits. In that way, either the value of signal $u_q(n)$ or value of multiplier $M(n)$ assigned to it (3) and (4) (the word length of binary signal $u_q(n)$ recorded after the quantizator is equal to $(N\text{-}M(n))$) is memorised.

In order to compare efficiency of different compression algorithms we can define a compression ratio G_k in accordance with information theory, referring number of information units Ψ of registered signal without compression $\Psi(u)$ to the number of information units of registered signal which is submitted to compression $\Psi(u_q)$:

$$G_k = \frac{\Psi(u)}{\Psi(u_q)} \tag{7}$$

3. COMPARATIVE ANALYSIS OF AN ADQ CODEC

The ADQ compression algorithm discussed in the previous section leads to a reduction in amount of digital measurement data without any information loss. The techniques of processing differences between adjacent samples, applied in the compression algorithm, make it similar to the known difference algorithms (Delta Modulation) [2,3,4]. The basic difference between the ADQ algorithm and other difference algorithms lies in the fact that it is the quantizer parameters that undergoes automatic adaptation dependent on dynamic properties of recorded signals. This way, signal $u_1(n)$ (i.e. the difference signal (1) amplified $m(n)$ times, where the value of $M(n)$ and, based on this value, the value of $m(n)$ are automatically selected depending on the dynamics of signal $u(t)$, according to (3)÷(5)) is quantized in an (N-$M(n)$)-bit quantizer. Note that for slowly-variable signals the differences between the values of subsequent samples are small and according to (4) and (5):

$$M(n) = N\text{-}1 \tag{8}$$

and, consequently, we get a 1-bit coder quantizer, which makes the coder ADQ close to the DM compression algorithm. For rapidly-variable signals the differences between the values of subsequent samples increase and the value of $M(n)$ tends to zero which implies an N-bit quantizer (no compression effect). For intermediate cases, depending on the current value of the difference between subsequent samples, the compression parameter $M(n)$ is selected automatically and this way the quantizer parameters are adapted.

Efficiency of the discussed ADQ compression algorithm is compared with the efficiency of other known lossless algorithms applied to the compression of measurement signals which have different dynamic properties. The operations of signal compression are made using the following algorithms:

- ADQ (adaptive difference quantization)
- Huffman's algorithm in static and adaptive version (dynamic),
- arithmetical in static and adaptive version,
- RAR,
- ZIP,
- combinations of the discussed algorithms.

Seven exemplary registered signals presented in Fig.1÷Fig.7 are submitted to compression. The signals in Fig.1÷Fig.3 illustrate registered, in long-term cycle, characteristics of temperature, pressure and relative air humidity changes. Signals in Fig.4 and Fig.5 present the displacement in vibration, but signals in Fig 6 and Fig.7 show characteristics of temperature and pressure changes in compressor.

Using different methods of lossless compression the obtained compression ratio G_k (7) is tabulated in Table 1. On the basis of listed results it can be stated that the biggest compression ratio is possibly achieved by combinations of ADQ and Huffman's or RAR algorithms. So, we can formulate a conclusion, that the usage of ADQ algorithm as

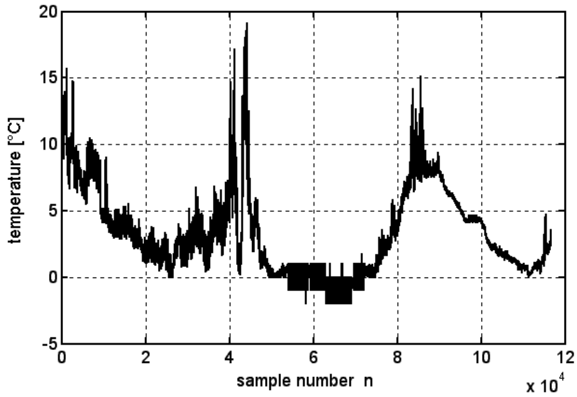

Fig.1. Exemplary, registered in long-term cycle, characteristics of air temperature changes - signal 1

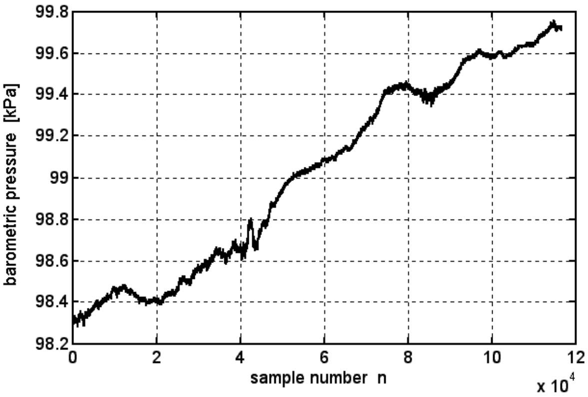

Fig.2. Exemplary, registered in long-term cycle, characteristics of barometric pressure changes - signal 2

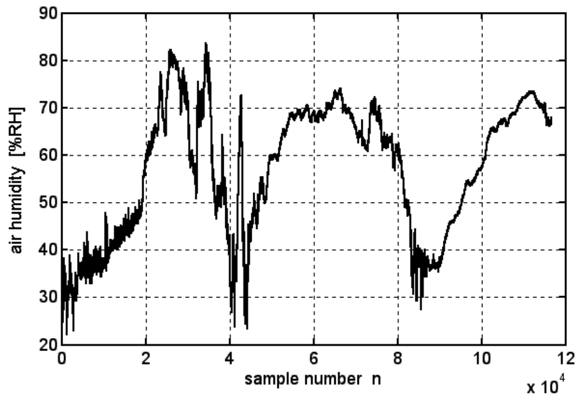

Fig.3. Exemplary, registered in long-term cycle, characteristics of air relative humidity changes - signal 3

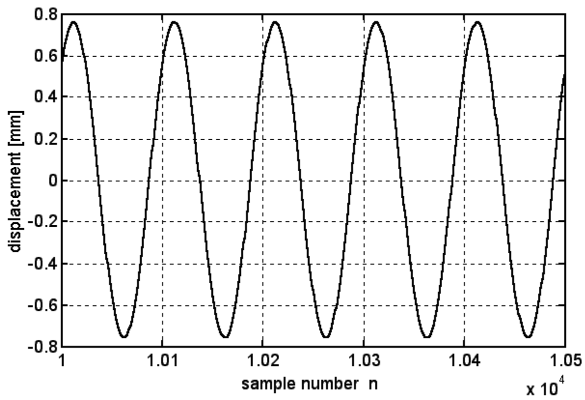

Fig.4. Fragment of exemplary registered signal of displacement in vibration - signal 4 (total samples number is equal 600 000)

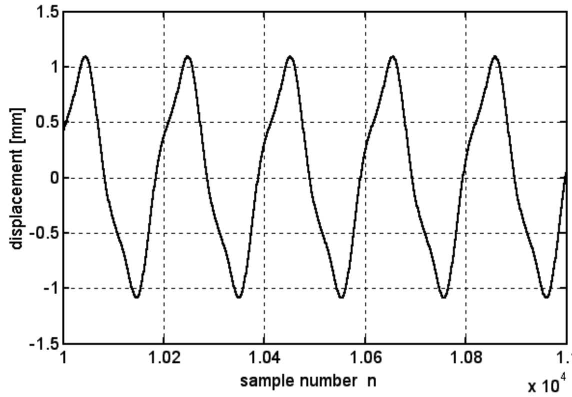

Fig.5. Fragment of exemplary registered signal of displacement in vibration - signal 5 (total samples number is equal 600 000)

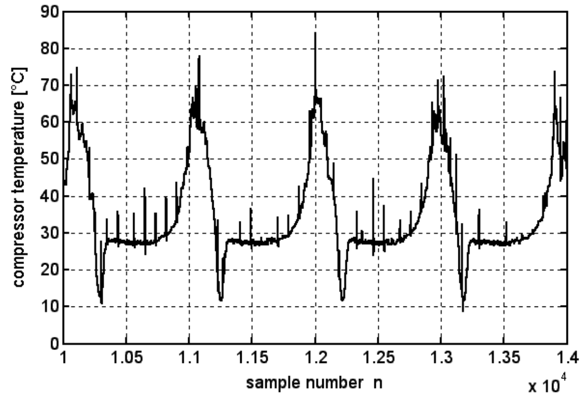

Fig.6. Fragment of exemplary registered signal of temperature changes in compressor - signal 6 (total samples number is equal 600 000)

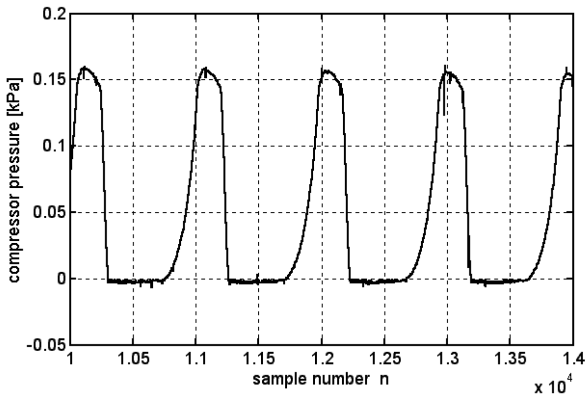

Fig.7. Fragment of exemplary registered signal of pressure changes in compressor - signal 7 (total samples number is equal 600 000)

an initial procedure preceding compression using Huffman's or RAR algorithms introduces profitable changes decorrelating and eliminating redundantion in the signal.

Application of other combinations of algorithms do not cause improvement of the compression effect on the same level. For a certain class of signals (signal 1 and signal 3) differences of compression ratio values made by ADQ, RAR and combined algorithms are not large. Considering that the time of ADQ algorithm realization in comparison with the other algorithms is short, the procedure of algorithm do not need performing neither the initial calculation of signal statistics nor information of the signal in time proceeding

Table 1. A list of compression ratio G_k (7) obtained for the tested compression methods and measuring signals.

	signal 1	signal 2	signal 3	signal 4	signal 5	signal 6	signal 7
samples number	116 710	116 710	116 710	600 000	600 000	600 000	600 000
file size [kbyte]	233 420	233 420	233 420	1 200 000	1 200 000	1 200 000	1 200 000
ADQ	2,84	4,60	1,87	0,83	0,96	1,49	2,55
ADQ + RAR	3,22	8,50	1,88	**1,81**	**2,00**	**2,40**	**5,62**
ADQ + Huffman	**3,71**	**10,27**	**2,28**	1,24	1,41	2,20	4,82
Huffman	1,48	2,04	1,17	1,68	1,28	1,75	2,32
Adaptive Huffman	1,60	4,02	1,02	1,60	1,23	1,72	2,40
Arithmetic	1,49	2,05	1,17	1,68	1,28	1,75	2,33
Adaptive Arithmetic	1,36	2,11	1,09	1,36	1,09	1,48	1,92
RAR	3,04	9,25	1,81	**1,82**	1,87	2,01	4,80
ZIP	2,02	7,90	1,32	1,56	1,23	1,75	4,41

the moment of processing. It is an attractive option for classical algorithms.

With regard to the dynamics of examined signals ADQ algorithm indicates a particular good effectiveness in application to the lossless compression of slow variable signals. Eventual appearing of short term impulses in measured signal do not cause essential worsening of compression ratio (i.e. signal 6).

4. CONLUSIONS

The results of the study on efficiency (compression ratio) of the discussed ADQ compression algorithm compared with known lossless algorithms heve been presented in the paper. The study was carried out taking into account the influence of dynamical properties of the measurement signals. The results obtained answer the question of how large compression ratio can be obtained for the proposed ADQ algorithm depending on the class of recorded measurement signals.

5. ACKNOWLEDGMENT

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