USING WAVELET TECHNIQUES FOR MULTIBEAM SONAR BATHYMETRY DATA COMPRESSION

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Multibeam sonars are widely used in applications like high resolution bathymetry measurements or underwater object imaging. One of the significant problems in multibeam sensing of the marine environment is large amount of data which must be transmitted from the sonar processing unit to an operator station using a limited bit rate channel. For instance, such a situation would be in the case when the multibeam sonar was mounted on the autonomous underwater vehicle operating on large depths and transmitting the data to the operator station using acoustic channel. In this context, the authors propose a method for multibeam sonar data size reduction. It relies on the use of wavelet decomposition technique combined with run-length and Huffman coding. The method was applied for lossy compression of raw bathymetry data which had been generated by a multibeam sonar processing unit in a form of a set of points in three-dimensional space. The performed tests revealed that without introducing the substantial distortion into the processed bathymetry data, the proposed approach allows to obtain better compression ratios than in the case of using standard lossy JPEG-like compression techniques.

INTRODUCTION

Multibeam sonars are widely used in marine environment surveillance [1], including detailed bathymetry measurement and seafloor mapping, underwater object detection and imaging, underwater infrastructure inspection etc. Current trends in sonar development involve the use of innovative transducer materials as well as application of sophisticated processing techniques, including focusing algorithms that dynamically compensate for the curvature of the wavefront in the nearfield and thus allow narrower beam widths (higher lateral resolution) at close ranges. Future developments will probably focus on “hybrid”, phase-comparison/beam-forming sonars, the development of broad-band “chirp” multibeam sonars, and perhaps synthetic aperture multibeam sonars [2].

One of the significant problems in multibeam sonar systems (MBSS) is large amount of data which have to be transmitted from the sonar processing unit to an operator station using a limited bit rate channel. In this context, application of an efficient method for compression of sonar recordings may be crucial for obtaining better sonar performance in many circumstances. Not long ago, Buelens *et al*. considered storage and compression as one of the most important computational challenges in processing of MBSS data [3]. However, since Ferguson's and Chayes's proposal of a binary file format for multibeam sonar data storage [4], there has been little development in the field of efficient MBSS data processing which would allow for fast, semi-real-time sharing of the results between diverse groups of interest such as fishermen, hydrographers or researchers. Apart from works of Wu and Zielinski [5], little attention has been paid to research related to algorithms for storing and archiving MBSS data that would allow for efficient browsing, analysis and visualization of collected information. Up to date, the compression of MBSS records is not widely being applied, either as implemented in the sonar hardware or in the specialized software.

The authors propose a method for MBSS data size reduction, which relies on the use of wavelet decomposition combined with run-length encoding (RLE) and Huffman coding. The preliminary verification of the method includes the comparison of its performance with standard lossy JPEG-like compression techniques.

1. MATERIALS AND METHODS

1.1. Discrete Wavelet Transform

The detailed description of wavelet decomposition may be found for instance in [6].

To provide a brief description of the wavelet analysis, it must be pointed out that it allows for decomposition of the investigated signal (or in general, in the discrete domain, of the data in a form of series of numeric values) into components which are localised both in time (offset) domain and in frequency (scale) domain. In this work, the Discrete Wavelet Transformation (DWT) was utilised, which may be described as a scheme of applying the set of lowpass and highpass filters combined with a decimation procedure, as it was depicted in Fig. 1. As a result, the representation of an investigated signal in a form of a tree of so-called wavelet coefficients is obtained (right part of Fig 1). The number of levels of decomposition may be chosen arbitrarily. A given wavelet coefficient value is related to the correlation between the analysed signal and so-called base wavelet (mother wavelet) shifted and rescaled properly.

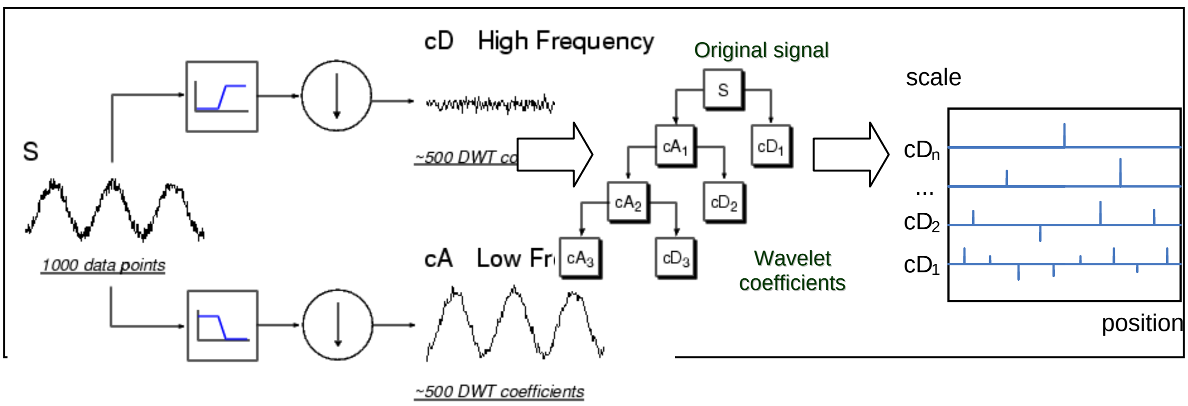


Fig.1. The scheme of Discrete Wavelet Transformation (DWT) procedure

1.2. Thresholding, RLE and Huffman coding

The concept of application of wavelets in data compression relies on the observation that after calculating the wavelet transform of the given data, many of wavelet coefficients are close to zero. Application of the thresholding modifies the coefficients to produce more zero values among them. In hard thresholding, which was applied in this work, many consecutive zeros occur in the obtained result. This operation leads to some loss of information contained by the processed data, but this is acceptable to some extent in many applications [6].

The result of data processing obtained by wavelet decomposition and thresholding can be now stored using less space as well as transmitted more quickly with applying the Run-Length Encoding – RLE algorithm and entropy coding compression [7]. RLE is a very simple algorithm of data compression in which the "runs" of data (i.e., the sequences in which the same data value occurs in a number of consecutive data elements) are represented as a pair of a single data value and its count. The next step is the Huffman encoding [8], in which the probabilities of occurrence of particular values (often referred as "symbols" or "characters") in the data are estimated. Then, the more frequently the symbol occurs in the data, the shorter code (in bits) is assigned to represent it.

1.3. Multibeam sonar data used in the method verification

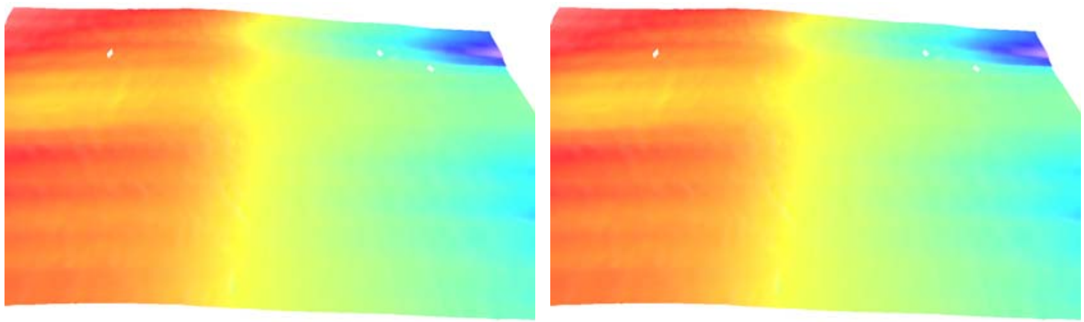
The data used in the experimental verification of the proposed compression procedure were acquired by the Kongsberg EM 3002 sonar in Gdańsk Bay region of the Baltic Sea in September 2007. The measurements were made for the purpose of seafloor investigation and imaging. The sonar operating frequency was 300 kHz, the width of beams: 1.5° x 1.5°, the transmitted pulse length: 0.15 ms, the echo sampling rate: 14.3 kHz. The bottom depth was in a range between 10 m and 100 m. For each swath, 160 beams covered the angle sector from -65° to 65°. Approximately 3000 recordings of multibeam soundings (swaths) were used as a test dataset in the verification of the proposed compression procedure.

Several types of information are contained in data recordings produced by the MBSS. They usually include beam backscattering strength data, bathymetry data, water column data (optionally), as well as beam geometry data, sonar configuration and calibration data, and external sensors data (such as CTD probe, GPS, compass, gyro and others). As the bathymetry data occupy the significant part of the space used totally by recorded data (this is true when the "water column" mode is turned off) and taking into account that bathymetry data are fundamental for many applications, only this type of data was processed in the current investigation. The bathymetry data were delivered by the MBSS system in a form of a set of (x, y, z) points constructing the model of seabed surface, where x denotes the horizontal along track co-ordinate, y - the horizontal across track co-ordinate, and z – the vertical co-ordinate. For each swath, 160 (x, y, z) points were recorded, each corresponding to one of 160 beams. The (x, y, z) co-ordinates were estimated by the MBSS software on the basis of the detection of the bottom echo start position for each beam echo signal (using threshold or phase method [9]) and taking into account the geometry of the experiment. Additionally, the ray refraction in water column, as well as the pitch, roll and heave stabilisation were also taken into account by the algorithm implemented in the MBSS firmware.

In the wavelet decomposition procedure, the Haar type [6] of mother wavelet was applied, and three levels of detail were used. The threshold value used in substituting the small wavelet coefficient values by zeros (see Subsection 2.2.) was chosen experimentally to assure the obtaining the sufficiently small value of root mean square error (RMSE) which was introduced by the compression procedure to bathymetry data.

2. THE RESULTS

Fig. 2 presents 2 images of a sample region of seabed surface, the first which was constructed using original MBSS raw bathymetry data (a) and the second was reconstructed from compressed data (b). The RMSE was assumed to be comparable to the accuracy of the multibeam sonar bathymetry measurements and was 1 cm in this case. It is visible that no difference between 2 images is recognisable in practice for this RMSE value.



a) b)

Fig.2. a) Seabed surface image obtained using the original MBSS bathymetry data, b) seabed surface image obtained using bathymetry data reconstructed after the compression

The next figures, Fig. 3, 4 and 5 present the RMSE values and the compression ratios obtained for wavelet compression method, and for comparison, for standard JPEG compression method, for *x*, *y* and *z* co-ordinates, for a sample data set of consecutive MBSS recordings. Fig. 9 presents total (for *x*, *y* and *z* co-ordinate data together) compression ratio for the same MBSS recordings. It should be pointed out that for the presentation purposes, the representative subset of the larger amount of the processed data was selected.

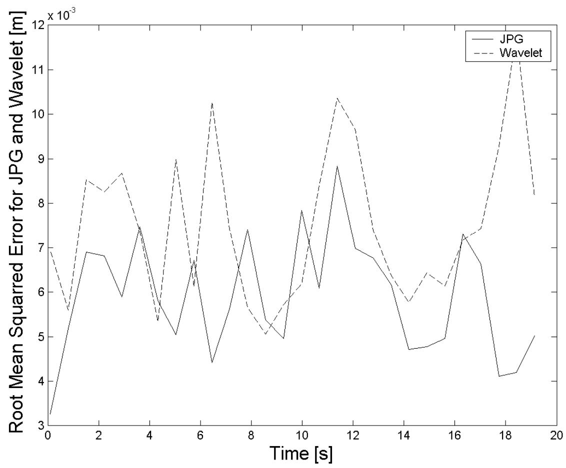


Fig.3. RMSE for compression of the seafloor bathymetry of *x* co-ordinate data for a sample set of consecutive MBSS recordings

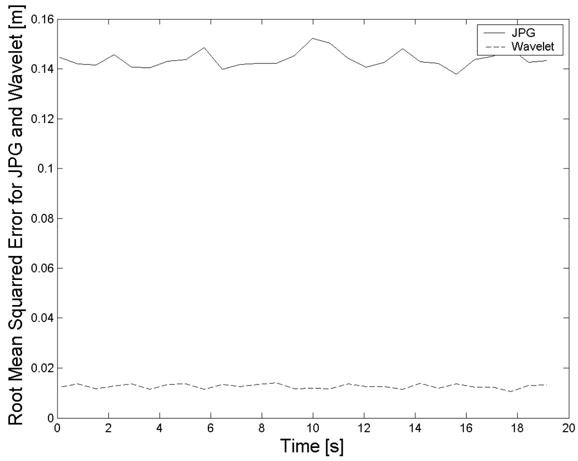


Fig.4. RMSE for compression of the seafloor bathymetry of *y* co-ordinate data for a sample set of consecutive MBSS recording

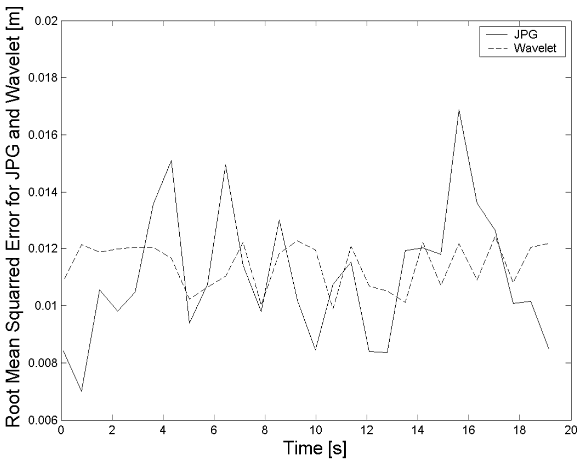


Fig 5. RMSE for compression of the seafloor bathymetry of *z* co-ordinate data for a sample set of consecutive MBSS recordings

The results of the obtained compression ratio defined as ratio between the size of compressed and original dataset are presented in Fig. 6, 7 and 8. The calculations were made with the assumed reconstruction error (RMSE) to be near 1 cm.

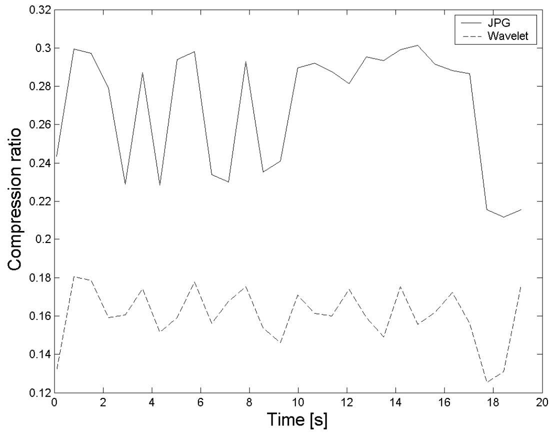


Fig.6. Compression ratio for seafloor bathymetry *x* coordinate data, for a sample set of consecutive MBSS recordings

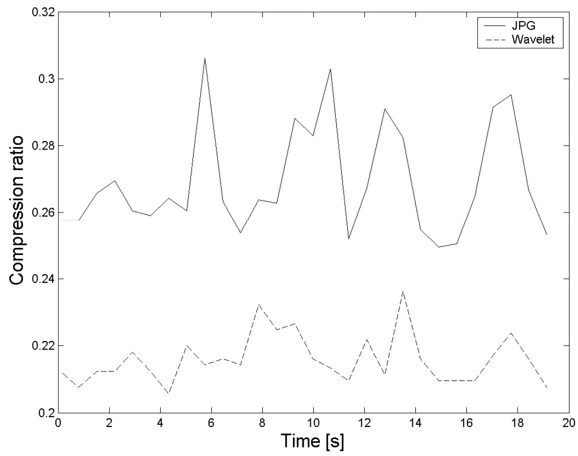


Fig.7. Compression ratio for seafloor bathymetry *y* coordinate data, for a sample set of consecutive MBSS recordings

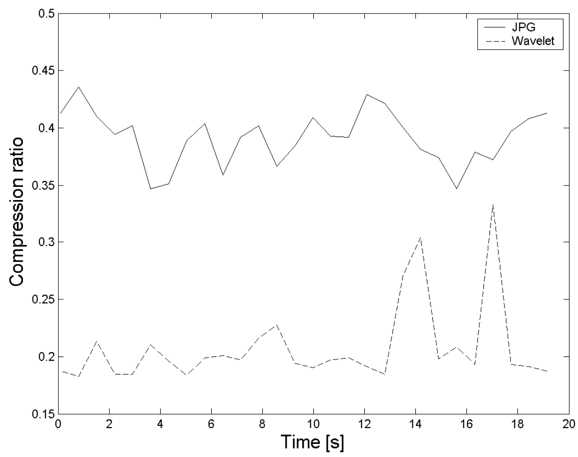


Fig.8. Compression ratio for seafloor bathymetry z coordinate data, for a sample set of consecutive MBSS recordings

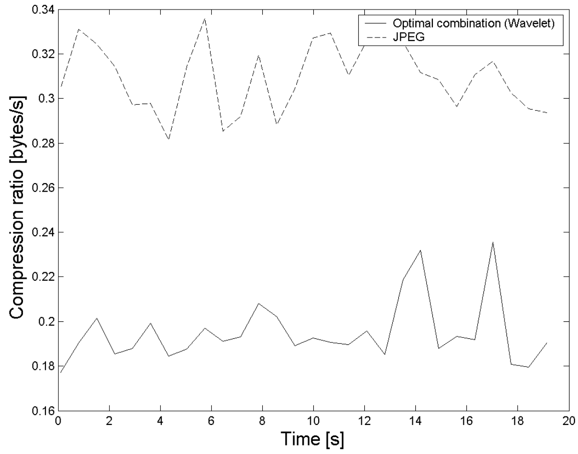


Fig.9. Total (for *x*, *y* and *z* coordinate data together) compression ratio for the same MBSS recordings as in Fig 7, 8 and 9

It is visible, that in all cases, the obtained compression ratio results for multibeam sonar bathymetry data are significantly better for the proposed wavelet compression technique than for standard JPEG method. The obtained mean compression ratio for all data used in the method verification was under 20% (for the presented data sample, it was 19,49%), while for JPEG method it was near 30%. For the sonar pinging rate of 10 per second, it allows for reducing the required transmission speed from approx. 9 kB/s to approx. 1.8 kB/s. In this context, we calculated the optimal, current baud-rate for the communication channel that is required to transmit the presented sample data – Fig. 10. It may be seen that to transmit raw bathymetry data from the sonar system, only 2 kB/s connection is required in general. That allows not only for significant reduction of the stored data size, but also makes possible the data transmission from sonar head and the processing unit to the operator station by wireless communication using the acoustic channel. In particular, the proposed technique may be useful when applied for AUV inspection with utilising MBSS system. It is worth pointing out that the proposed approach would make many AUV surveys much easier due to enabling the continuous communication between the sonar and the operator station and making possible the remote, real-time visualisation of the data acquired by AUV.

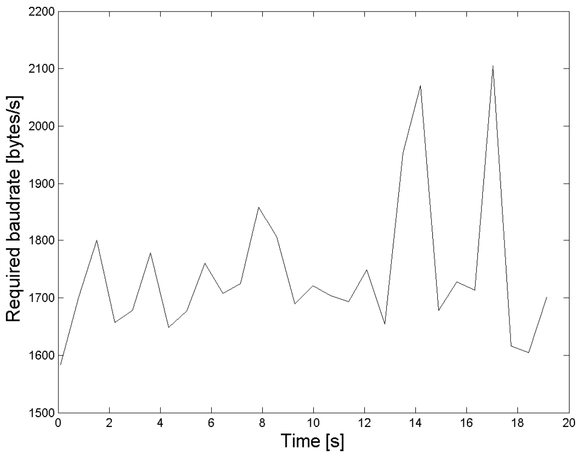


Fig.10. Required current baud-rate

3. CONCLUSIONS

The method for multibeam sonar raw bathymetry data size reduction was presented. The method relies on the use of wavelet decomposition technique combined with run-length encoding and Huffman coding. It has been shown that for the proposed method, the compression ratio results are significantly better than for standard JPEG method. The proposed technique may be useful when applied for AUV-based measurements utilising MBSS systems, as it enables for the continuous communication between the AUV-mounted sonar and the operator station by acoustic channel, and for the remote, real-time visualisation of the acquired data.

Further work should include the investigation of other compression approaches and methods, like Principal Component Analysis for instance.

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