REVERSIBLE INTEGER WAVELET EVALUATION FOR DEM PROGRESSIVE COMPRESSION

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1. INTRODUCTION

Web-based GIS visual simulation systems have to handle voluminous elevation data sets, but the limited network bandwidth is a bottleneck. One commonly used method to solve this problem is that the data servers provide DEM multi-scale representations which are stored and compressed independently, and transmit corresponding scale data according to the needs of clients (Rishe et al., 2004). However, in this method, there are a lot of redundant data between different resolutions. An ideal way is to employ the multi-scale lossy-to-lossless progressive compression based on wavelet transforms, which eliminates the redundant data between resolutions, and easily allows the transmission of low resolution versions firstly, followed by transmissions of successive details. The integer lifting wavelet maps integers to integers and permits DEM lossless reconstruction with minimal memory usage and low computational complexity. Among the different integer wavelet transforms, which one is the most suitable to the DEM multi-scale progressive lossless compression with high accuracy in every resolution has not been set forth in relative papers so far as we know (Adams and Kossentini, 2000; Liu et al., 2005). Thus, in this paper, 15 different reversible integer wavelets are compared their accuracy performance of maintaining the main original terrain characteristics in different resolutions when multi-scale compressing the DEM data progressively. To better evaluate the wavelets' accuracy performance, two accuracy appraisal methods are proposed. At the same time, their lossless compression performance and computational complexity are also considered. In addition, factors affecting the performances are discussed, supported by both experimental data and theoretical arguments.

2. EXPERIMENTS ILLUSTRATION

The reversible integer wavelet transforms considered in this study are based on the lifting framework. The 15 evaluated reversible integer wavelets are 5/3, S, 2/6, SPB, 9/7-M, (2, 4), (6, 2), 13/7-T, 5/11-C, 2/10, 5/11-A, 6/14, SPC, 13/7-C and 9/7-F transforms. For evaluation purpose, the JPEG2000 open source software OpenJPEG lib (version 1.2) (Janssens, 2007) was employed to lossless compress DEM data. In order to facilitate our testing, the original transform-related code in the software was replaced with new code, because much of the functionality required for our analysis was not present. After the integer lifting transform, the coefficients with multi-resolution characteristic are bitplane and entropy coded.

3. ACCURACY PERFORMANCE APPRAISAL MEHHOD AND EXPERIMENTAL RESULTS

To better measure these wavelets' accuracy performance of maintaining the main original terrain characteristics in different resolutions, two accuracy appraisal methods were proposed because currently there is no uniform appraisal criterion about the DEM accuracy of different resolutions. The first appraisal method is to compute the forward mean distance from the low resolution DEM surface to the original DEM surface and the backward mean distance from the original DEM surface to the low resolution DEM surface. These two distances are not equal because the mean distance between two surfaces is not symmetric. Obviously, the least the two mean distances are, the better the accuracy performance of the low resolution data is. The other appraisal method is to compute the DEM low resolution's mean curvature. It has been proved that the terrain representation error's RMSE (root mean square error) value has a positive quantitative-relationship with the DEM resolution and mean curvature. For a specific resolution, the least the mean curvature of the low resolution data is, the better the accuracy performance is.

According to the above two accuracy appraisal methods, various experimental results were obtained about these wavelet transforms' accuracy performance. Since the different resolutions of DEM data are owing to the decomposition successively of the low-pass subband signals, it is enough to only measure the low resolution with 1 level wavelet decomposition. Ten DEM data coming from different terrain types were employed, and each was 1 level decomposed by each of all the 15 wavelets. Each of these 150 low resolution data was computed the two mean distances and the mean curvature. Through comparing via charts and tables, it was found that several wavelets were particularly well in the accuracy performance for all test DEM data. They are the S, 2/6, 2/10, SPB, SPC and 6/14 wavelets..

4. LOSSLESS COMPRESSION AND COMPUTATIONAL COMPLEXITY COMPARE RESULTS

These wavelets' high lossless compression performance and low computational complexity were also considered. To the lossless compression performance, among the 2/6, S, SPB, SPC, 2/10 and 6/14 wavelets, the ratios of the average compressed file sizes using these six wavelets separately on the ten DEM data are 1.000: 1.1540: 1.0206: 1.0021: 0.9859: 0.9993 in turn. To the computational complexity, when all multiplications are converted to shift and add operations, the operation counts of each transform step for the 2/6, S, SPB, SPC, 2/10 and 6/14 wavelets are 7, 3, 11, 15, 16 and 16 in turn. Therefore, as a trade-off, the 2/6 transform is the best one in the low computational complexity and high lossless compression performance.

5. EXPERIMENTAL RESULTS CONCLUSION

Therefore, considering all above factors, the 2/6 integer wavelet was chosen to be the most suitable one to the DEM multi-scale progressive compression.

6. THEORETICAL ARGUMENTS

Lastly the factors that affect these performances were examined from wavelet theoretical sides. To the accuracy performance, since the different resolutions of the DEM data are owing to the decomposition successively of the low-pass subband signals, the dynamic range of the low pass transform coefficients is an important factor. The worst-case dynamic range growth of a wavelet' low pass transform is an approximate function of the 1-norm of its analysis filters, so the 1-norms of the wavelet's low-pass analysis filter is the most important factor affecting the accuracy performance. This point has been proved by the experimental results. For example, the 2/6, S, SPB, SPC and 2/10 wavelets perform well in the accuracy performance for all test DEM data, because the 1-norms of their low-pass analysis filters equal 1 and their transform coefficients have no worst case dynamic range growth in the low pass channel. Besides, the shape of the wavelet's analysis scaling function is another important factor to affect the accuracy performance, which has been proved by the 6/14 transforms. To the lossless compression performance and computational complexity, the affecting factors have been covered by many researches, such as the number of vanishing moments, the regularity and the lifting steps, which also have been proved by our experiments.

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7. CONCLUTION

Thus, through experimental data and theoretical arguments, the 2/6 integer wavelet was found to be the most suitable one for the DEM multi-scale progressive compression among the reversible integer wavelet transforms compared. In addition, several factors affecting the precision and compression performance were also found, which could be a guide to design new and more effective wavelet transforms for the DEM multi-scale progressive compression.

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