PROGRESSIVE COMPRESSION OF DIGITAL ELEVATION DATA USING MESHES

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ABSTRACT

In this paper a new Digital Elevation Map (DEM) image compression algorithm is proposed. DEM image can be threated as a grayscale image, whose pixel values are the elevation values of the map points. The grayscale DEM image is compressed using an adaptive wavelet based image compression algorithm. The method, which is an extension of the progressive mesh compression takes advantage of the multiresolution property of the wavelets while coding the map images. This makes it possible to decode different resolutions of the map from the encoded bit stream providing a multiresolution display of a given map. Experimental results are presented.

1. INTRODUCTION

Several different GIS Data Formats exist [1]. These data formats can store informations including;

- geographic information, which provides the position and shapes of specific geographic features,
- attribute information, which provides additional non-graphic information about each feature, and
- display information, which describes how the features will appear on the screen.

As seen on Figure 1, a typical digital elevation representation in a digital map consists of 3D point clouds (1a) and their connectivity information (1b). Therefore geospatial data is similar to 3D mesh representation in many ways. The information in a map correspond to the geometry and connectivity information of 3D mesh models respectively [2]. Coordinate X, Y locations of a *Digital Elevation Model (DEM)* can be stored as the X, Y coordinate of a mesh vertex and, moreover, the elevation of the particular point can be stored as the Z coordinate of the vertex. Therefore, digital elevation data can be treated as mesh models. A mesh like representation of a digital elevation data has several advantages. For example calculation of the slope and the aspect, which are crucial for the applications like fire propogation calculation [3], can be easily done from a 3D mesh like representation of a map.

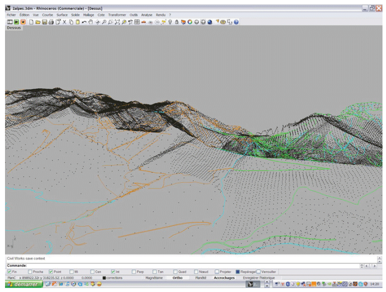
As the area represented by the map file gets larger, the amount of data stored in the map file also increases. Therefore ways of efficiently storing and transmitting those data become a crucial issue. Since the digital elevation data, can be represented as a 3D mesh, static mesh compression techniques given in [4], which compresses 3D mesh models using image compression tools, is very suitable for the compression of this data. In [4] it is proposed that, 3D mesh models can be converted to images using orthographic projection, that can then be compressed using standard image data compression algorithms. Digital elevation data is very suitable for orthographic projection in its nature. One can directly use the elevation data as the pixel values of the projected image and the X, Y value of each node as the pixel location. As a result, it is straightforward to create 2D images from maps. Actually grid-like digital elevation data is in a raster format itself. The connectivity information of a map can also be defined directly for the pixel neigborhood therefore there is no extra need for the trasmission of the connectivity information like in 3D meshes.

Here an adaptation of the compression algorithm given in [4] will be used. The DEM image is transformed using adaptive wavelet transform given in [5],[6],[7]. Then the transformed image is fed into SPIHT encoder and progressively encoded. The encoded bitstream is progressive as different resolutions of the DEM image can be reconstructed from different length of the bitstream.

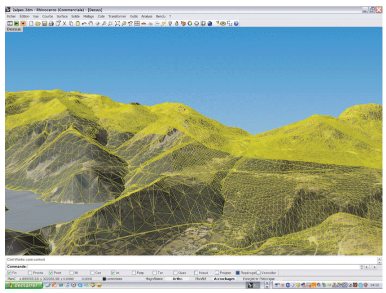
This paper is organized as follows: In Section 2, the relation between the structure of 3D mesh models and the digital maps is explained. In Section 3, map compression algorithm is presented. Compression results are given in Section 4.

2. RELATION BETWEEN 3D MODELS AND MAPS

A 3D mesh model is composed of two basis parts; geometry and connectivity information. Geometry information describes the places of vertex points, which can be counted as the signal sample points. Connectivity data defines how these sample points are connected to each other in other words how those points create surfaces. As seen in Figures 1 and 2, vertex points on both a 3D mesh model and a terrain map do not need to be regularly positioned. Large planar surfaces in both 3D models and maps can be represented by a few large triangles and the areas with fine details can be represented by a large number of small triangles. Therefore the sampling stucture may not be regular. This irregular structure is one of the reason that standard natural image compression algo-



(a)



(b)

Fig. 1. Irregular mesh like representation of digital elevation data. (a) Sample points as point clouds, (b) connectivity information.

rithms requiring regular sampled data can not be directly used for coding map data. However it is possible to use standard image coding methods with irregular map data by processing the data in a proper manner. Assume that a 3D vertex point V in 3D space is represented as follows:

$$V = [x, y, z]. \tag{1}$$

By orthogonally projecting this point to a selected plane, we can create a regularly placed data. For example, asume that our projection plane is the horizontal xy plane. In this case the position of the image pixel will be determined by x, y components of the vertex V and the pixel value will correspond to the z component as follows:

$$I(x, y) = z. \tag{2}$$

Obviously, to obtain discrete pixel locations on a regular grid, x, y values in Equation 2 should be quantized. A more detailed explanation of the image formation procedure can be found in [4].

3. DIGITAL MAP COMPRESSION

The main compression algorithm that is used here is Set Partitioning in Hierarchial Trees (SPIHT) [8]. SPIHT is wavelet transformation (WT) based compression algorithm that uses a multiresolution decomposition of the input image. Different filter bank structures such as; orthogonal, biorthogonal,

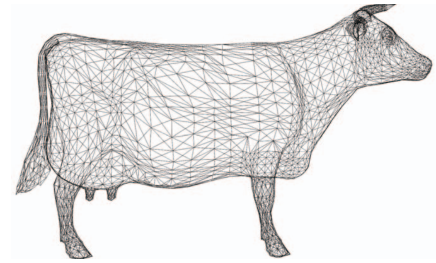


Fig. 2. Irregular 3D mesh model of a cow.

daubechies etc. can be used during this multiresolution analysis of the input image. However, as the relation between the pixels of the projected map image is different from natural images, the direct application of natural image compression methods would not efficiently work.

In this paper we introduce an adaptive prediction structure similar to the one introduced in [4]. At each prediction level the pixels are predicted from their connected neighbors at the low pass channel i.e. the LL image of the WT. The prediction structure in a lifting WT has to be adaptive because a grid point (a pixel) may not have a constant number of neighbors at the LL image. As a result, the prediction structure always changes.

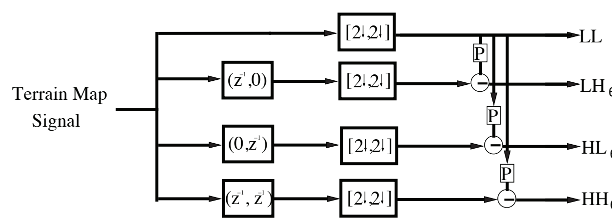


Fig. 3. Polyphase structure and the prediction stage, that is used in the wavelet transformation (WT).

The polyphase structure in the lifting wavelet transformation that we used in the compression of the terrain maps is given in Figure 3. The LL image is used as the 'lowpass channel' and all predictions are done using the values in this channel. After one level of wavelet tranformation LL image contains the pixels $I(2x, 2y),\ where\ x \in [0, N/2 - 1]\ and\ y \in [0, M/2 - 1]$. N, M are the size of the image in horizontal and vertical directions respectively. The prediction and prediction error for a pixel in horizontal and vertical directions is calculated as follows;

$$LH_p(x, y) = 0.5(LL(x, y) + LL(x + 1, y)), \tag{3}$$
$$LH_e(x, y) = LH(x, y) - LH_p(x, y), \tag{4}$$
$$HL_p(x, y) = 0.5(LL(x, y) + LL(x, y + 1)), \tag{5}$$
$$LH_e(x, y) = LH(x, y) - LH_p(x, y). \tag{6}$$

On the other hand, since the pixel in the HH subband have

4 neighbours in the LL channel instead of two (as the case for LH an HL channels), here the filter structure changes. Instead of giving equal weight to each neighbour, an adaptive scheme [5],[6] whose weights are decided accoring to the derivates in the diagonal direction is defined. For the pixels in the HH channels, derivatives on 45 degree and 135 degree directions are calculated as follows;

$$\Delta HH_{45}(x,y) = |(LL(x,y) - LL(x+1,y+1))|, \quad (7)$$
$$\Delta HH_{135}(x,y) = |(LL(x+1,y) - LL(x,y+1))|. \quad (8)$$

Then the prediction and the prediction error for a pixel in HH channel is;

$$HH(x,y)_p = \frac{\Delta HH_{135}(x,y)(LL(x,y) + LL(x+1,y+1))}{\Delta HH_{45}(x,y) + \Delta HH_{135}(x,y)} + \frac{\Delta HH_{45}(x,y)(LL(x+1,y) + LL(x,y+1))}{\Delta HH_{45}(x,y) + \Delta HH_{135}(x,y)}, \quad (9)$$
$$HH(x,y)_e = HH(x,y) - HH(x,y)_p. \quad (10)$$

Filter given in Equation 9 adapts itself inversely proportional to the derivatives, which means it favors the smooth transitions on the map. Since there are no occlusions on the map image, it less probable to encounter sudden jumps among the pixel values. Therefore favoring the smooth transitions would give better results.

After creating the wavelet transformed map image, it is fed to the SPIHT coder and the data is bitplane encoded [8]. From different lengths of the SPIHT bitstream, different resolutions of the digital map can be reconstructed [8]. Therefore SPIHT based coding of the map images, is a progressive compression scheme. The results of reconstruction of the map image from different length of the SPIHT bitstream is given in Section 4. All the operations defined above are reversible. Therefore, perfect reconstruction is possible.

4. RESULTS

The algorithm mentioned in Section 3 is tested on two free terrain map models called *bay* and *SAfrica*. For comparison we also performed tests using the JPEG standard. Commercial JPEG encoders can encode 8 bit grayscale images. However the pixel values of the map image are exceeding 8bits. Therefore the map image is divide into two images, one of which stores the most significant 8 bits of the map and the other one stores the least significant 8 bits. These two images are compressed seperately.

PSNR of the image storing the most significant 8 bits of the map, affects the total PSNR more than the PSNR other image. Therefore the first image is compressed in a lossless manner. The compression results for *bay* and *SAfrica* map models using the proposed algorithm and JPEG are given in Figures 4 and 5. From the figures it is seen that the proposed algorithm is superior to the JPEG coder.

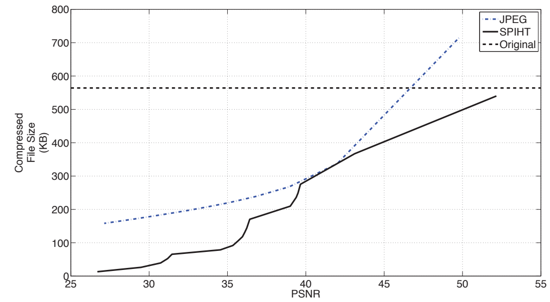


Fig. 4. Bay terrain model compression results. The zip compressed terrain model has a file size of 564 KB

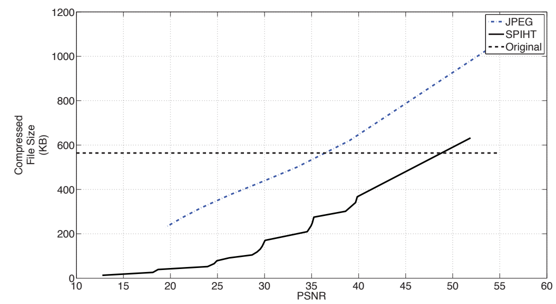


Fig. 5. SAfrica terrrain model compression results. The zip compressed terrain model has a file size of 820 KB

As mentioned in Section 3, the proposed SPIHT based compression algorithm is a progressive coder. As the decoder receives more bits from the encoder it can progresivelly update the map image and create a finer resolution reconstruction. In Figure 6, map images reconstructed form different sizes of SPIHT bitstream can be seen. Figure 6 also shows that, the reconstruced image with PSNR of 30db is visually same as the original image. On the other hand, for more precise tasks, PSNR of more than 40 can be used both

5. CONCLUSION

In this paper we introduced a new adaptive predictive wavelet based SPIHT coder for DEM images. The adaptive wavelet transformation step worked well in the case of DEM images since the transitions are smooth (exceptions always exists e.g. cliff). Therefore directional predictions work very efficiently. Different from natural images there is no occlusions, which prevents us to face with edges due to occluded object boundaries.

The results given in section 4 shows that compression ratio between 5-10 can be achieved without introducing any visual distortortion. The introduced algorithm is novel in the sense that there is no progressive DEM image compression

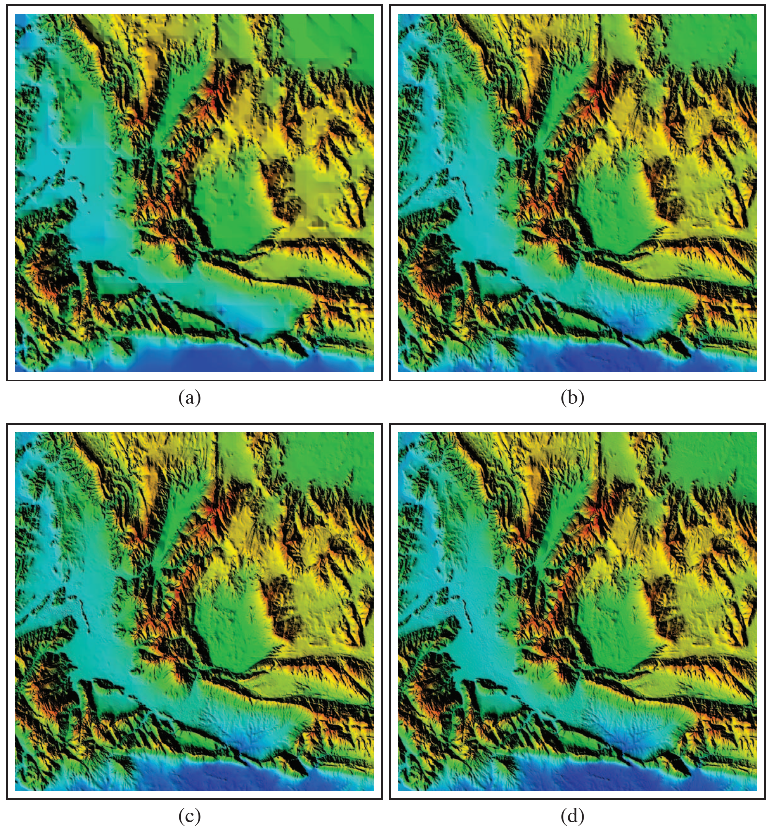


Fig. 6. Map image reconstructed from; (a) 36.8 KB, (b) 137KB and (c) 238 KB of SPIHT bitstream. (d) The original map image. The reconstructed images have (a) 18.69, (b)29.76, (c) 35.07 db PSNR

tool available in the literature. We believe that, this property will be beneficial especially in the streaming based visualization of the map images in mobile applications. The user can first see a low resolution of the map and then detail level of the map can be further improved as in the Google Earth type visualization.

Another usage area can be the composition of the thumbnails. Most of the websites that are serving DEM maps, first give representation of a big area composed of the thumbnails of small area maps. These thumbnail can be composed from small parts of the SPIHT bitstream. As the user clicked on a point in the map, the detail streams of area of intrest can be requested from the server and that part of the map will be upscaled and showed in detail.

6. REFERENCES

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