A NEW TERRAIN DATA COMPRESSION SCHEME FOR INTERACTIVE TERRAIN VISUALIZATION SYSTEMS

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Abstract: Over the last years, there has been a great development on real time terrain visualization applications using remote databases. One of the main problems that these applications must face is the storage and transmission of terrain data. Despite the considerable bandwidth increase of internet connection during last years, the large amount of data to be transmitted can easily saturate these connections. On other hand, since data must be stored in the client side, clients need a considerable storage space. In this context, we propose a new compression scheme that solves or minimizes these problems. It is based on JPEG2000 standard; however, the wavelet analysis and synthesis algorithms are modified to allow efficient transmission and reconstruction of terrain data by using tiled pyramids multiresolution techniques. A comparative study including current techniques shows that the proposed scheme obtains a better compression ratio of the terrain data, reducing the storage space and transmission bandwidth needed, achieving a better visual quality of terrain data reconstructed after data decompression.

1 INTRODUCTION

Real-time terrain visualization is a very active research field in the area of computer graphics. Some applications examples in this area are driving or flight simulator, cartography applications or virtual worlds visualization.

These applications usually use a client-server architecture to transmit terrain data over the Internet. In this architecture, the terrain visualization component runs on the local host (client) and the terrain database component runs on a remote server. In order to visualize the terrain data, the most commonly used strategy is to define a multiresolution hierarchy for a data set, splitting each level of resolution of the terrain data into a set of fixed-size regular tiles (rectangular non-overlapping blocks). This process is known as tiling.

All the tiles form a tiled pyramid as shown in Figure 1 - a. This figure shows four resolution levels of a terrain dataset. Each resolution level is split into tiles of the same size, so the number of tiles decreases with the resolution level.

In order to visualize the terrain data, initially a lower resolution tile is transmitted. If more resolution is needed, this tile is replaced with the next level of resolution tiles. This process is repeated until required visual quality of the terrain is reached.

This structure was initially used by Goss and (Yuasa, 1998) and (Cline and Egbert, 1998). This, and similar structures (Okamoto, de Mello and Esperança, 2008) have been used later in multiple works because allow a progressive and independent transmission of the different terrain regions.

The data structures commonly used in these applications are heightmaps, that describe the terrain surface, and texture images that provide a more realistic appearance of the terrain. Both of them can be encoded as an image. Therefore, techniques used for texture compression can also be applied to compress the heightmap data.

JPEG2000 image compression standard (JPEG Committee, 2004) has been proved to be one of the best image compression algorithms available for the moment. However, in order to use this standard in a terrain visualization application, several problems must be solved. One of these problems is due to the fact that the original JPEG2000 standard does not properly suit the tiled pyramid scheme used to organize data in terrain visualization applications.

In this paper, we propose a new data compression scheme for remote terrain visualization systems. We have performed a comparative studio

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including current techniques. The results show that the proposed compression scheme obtains a better compression ratio of the terrain data, reducing the storage space and the required transmission bandwidth and providing a better visual quality of terrain data in real time visualization. Moreover, this new scheme fits the tiled pyramid that terrain visualization applications usually use to manage large terrain databases.

2 RELATED WORK

Nowadays, compression schemes based on discrete wavelet transform (DWT) have been proved to be the most efficient way to compress images. Some of these schemes can be found in the survey done by Sudhakar, Karthiga and Jayaraman (2005).

Several authors have combined data compression methods with multiresolution schemes to reduce the bandwidth and memory requirements for terrain visualization applications. For example, Gioia, Aubault and Bouville (2004) and Kim and Ra (2004) use wavelet transform for geometry reconstruction of the terrain over the network, and Royan, Gioia, Cavagna and Bouville (2007) use wavelet transform for coding and transmitting the terrain geometry.

These works use different techniques that are able to provide high rates of compression, progressive transmission and random spatial access. Among them, the JPEG2000 standard compression scheme can be emphasized. One example of its use is the work of Lin, Huang and Chen (2007), that uses JPEG2000 standard for 3D geometric objects compression and transmission.

Many other authors have developed compressed geometry representations, but in most cases they are oriented to achieve high compression rates instead of focusing on fast algorithms, more suitable for real time visualization (Alliez and Gostman, 2005).

3 DATA COMPRESSION

As it was discussed in the previous section, JPEG2000 standard is one of the best image compression schemes. The purpose of our work is the adaptation of JPEG2000 standard for its use in terrain visualization applications, and the evaluation of its performance with respect to current techniques. For comparison purposes, we have implemented four possible strategies.

3.1 Strategy 1: No Information Reused

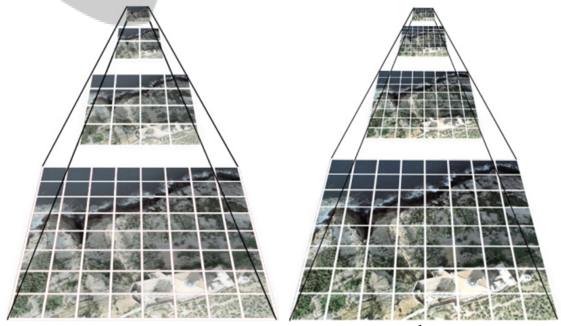
This strategy consists in generating a different image for each level of resolution of the tiled pyramid (Figure 1 - a). Each one of these images are split in tiles, which are transmitted and decompressed in an independent way, as isolated images, without using information of tiles belonging to lower levels of resolution, which were previously transmitted.

The total amount of data for the whole tiled pyramid represents an overhead of 33 % with respect to the image with the higher resolution level of the tiled pyramid (Goss and Yuasa, 1998).

This strategy is usually used for terrain visualization in applications like Google Earth (Google, 2010).

3.2 Strategy 2: JPEG2000 with Tiling

JPEG2000 standard allows splitting an original image into a group of smaller regular images that are then compressed and transmitted in an independent way. The compression/decompression scheme of JPEG2000 tiling is shown in Figure 2. In this compression scheme, the image is split into tiles and the wavelet transform is applied to each tile in an independent way (JPEG Committee, 2004).



a b

Figure 1: a) Tiled pyramid with 4 different resolution levels. b) JTiles in Tiled Pyramid.

We will denote the tiles generated by the JPEG2000 compression scheme as JPEG2000 tiles (JTiles), in order to avoid confusion with the tiles used in a tiled pyramid.

The main problem of this scheme is that the number of JTiles generated at every resolution level is always the same, and its size is decreased (Figure 1 - b), so this scheme do not match with the tiles used in a tiled pyramid (where the number of tiles decrease and its size remains constant) and it will be necessary to transmit and combine several of these JTiles to obtain an equivalent tile of the tiled pyramid. These differences can be observed comparing Figure 1 - a and Figure 1 - b.

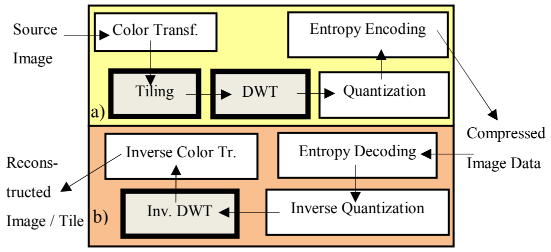


Figure 2: JPEG2000 standard with tiling scheme, a) Compression, b) Reconstruction.

This strategy is used by Hayat et al. (2010) to do online 3D terrain visualization.

3.3 Strategy 3: JPEG2000 without Tiling

If the tiling process is not used, then JPEG2000 generates only one JTile for each resolution level of the tiled pyramid. If a region of this JTile is reconstructed in an independent way, visual artifacts appear at the borders of these regions, as we will show in section 4.1.

This is due to the fact that in the analysis process JPEG2000 uses information different from the used in the analysis process and in the synthesis process. In the analysis process, all the image data are used to generate all the wavelet coefficients, but in the synthesis process (in order to reconstruct a tile of the tiled pyramid in an independent way) only the coefficients placed inside the region matching the tile are used to reconstruct this terrain region, without using neighboring coefficients that were used in the analysis process.

The compression/decompression scheme is the same shown in Figure 2, but now without using the tiling process.

3.4 Strategy 4: New Scheme

In order to solve the problems of the previous strategies, we have modified the compression scheme as is shown in Figure 3 - a. This scheme is similar to the one used by JPEG2000 standard; the main differences are the image tiling process and the wavelet transform application.

A wavelet analysis example following this scheme is shown in Figure 4. Before each wavelet transform step is applied, the image is split into several tiles of fixed size (Figure 4-a). (JPEG2000 standard initially splits the image into JTiles only once). Then, a 2D analysis filter is applied to each tile, generating four coefficients sub-bands: a low-pass sub-band (LL) and three high-pass sub-bands (HL, LH and HH) (Figure 4-b). The coefficients of the high-pass sub-bands are grouped into code-blocks, quantized and entropy encoded in an independent way, similarly to the way JPEG2000 standard does. Before a new wavelet transform step takes place, all low-pass sub-bands (LL) are grouped into a lower resolution version of the image (Figure 4-c). This process is repeated until this lower resolution version size is smaller than the tile size (Figure 4-d, 4-e, 4-f).

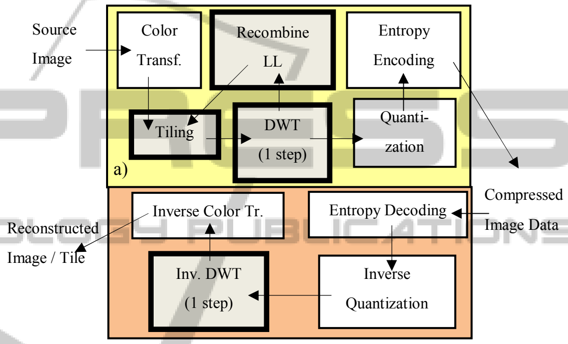


Figure 3: New scheme a) Compression, b) Reconstruction.

In order to reconstruct these tiles, the inverse process takes place in a progressive way (Figure 3 – b), but using the inverse DWT module properly modified to apply only one step. Once a tile has been reconstructed, any children tile can be reconstructed by decompressing and applying one wavelet transform step, joining the coefficients of the children tiles sub-bands HL, LH and HH with data of the father tile sub-band LL.

This tile reconstruction is perfect, without visual artifacts in the region frontiers, because the same coefficients are used for the synthesis and the analysis process of the wavelet transform, avoiding the use of coefficients that belong to neighboring tiles in both processes, unlike the JPEG2000 standard scheme used in strategy 3. Additionally, these modifications allow the number of generated tiles to fit in the tiled pyramid.

These modifications slightly increases the time required to compress the data with respect to the original compression scheme, due to the process to recombine the LL sub-bands. Nevertheless, the compression of the data is done off-line, and therefore it does not affect to the performance of the terrain visualization application.

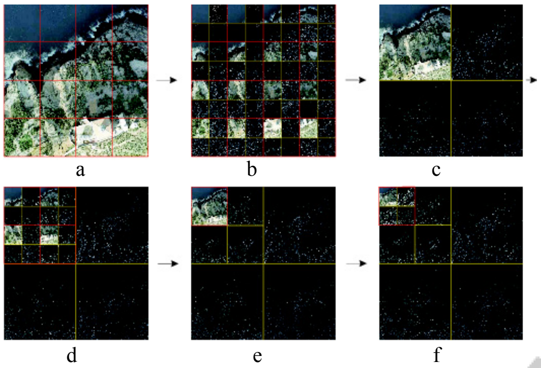


Figure 4: Decomposition process over an image.

The time requiring for decompress the data is similar to the original compression scheme, the difference is that in the original scheme all the steps of the inverse DWT were applied consecutively and now they are applied in an independent way.

4 EVALUATION AND TESTING

A generic application of terrain visualization has been used to compare the different compression scheme strategies. This application consists of performing a real time fly over different terrain databases using different visual quality parameters. This application allows taking top view photos and user point of view photos of the terrain surface and storing them for analysis.

The terrain database used for this application is formed by a set of terrain textures and heightmaps that have been compressed using the different compression scheme strategies described in the previous section.

Different tests have been performed on these databases: visual artifacts, lossless compression ratio and lossy compression root mean square error.

4.1 Visual Artifacts

Terrain visualization systems with remote databases need to reconstruct every tile of the tiled pyramid in an independent way. When strategy 3 is used (JPEG2000 without tiling scheme) to reconstruct a terrain region in an independent way, visual artifacts will appear in the frontiers of these regions. These artifacts do not appear in the other considered strategies.

This test checks visual artifact impact for the different strategies. In order to achieve this goal, our terrain visualization application has taken top view photos of the terrain database that have been lossless compressed using the different compression strategies. The terrain images have been reconstructed by regions in an independent way.

Figure 5 shows a representative example of the visual artifacts obtained when using strategy 3. Figure 5-a shows an example of user point of view inside terrain visualization application. Figure 5-b shows the terrain dataset (at high resolution) corresponding to the terrain region viewed by the user at that moment. Figure 5-c and 5-d show the tiles used from the tiled pyramid at that user point of view by strategy 3 and 4 respectively. Figure 5-c shows visual artifacts in the frontiers between terrain regions of the same level of resolution. These visual artifacts do not appear in Figure 5-d. These differences have been emphasized by red ellipses.

In order to evaluate the visual quality in a quantitative way, five resolution levels of the terrain surface (Figure 5) have been reconstructed by tiles of the same resolution in an independent way, and theirs root mean square error (RMSE) have been measured in relation to the high resolution terrain surface.

Table 1 shows the results for the strategy 3 and 4. Strategy 1 and 2 results are similar to the strategy 4 ones, because in these strategies do not appear visual artifacts.

Version 0 corresponds to the lowest level of resolution, and version 4 corresponds with the highest resolution reconstruction.

Table 1: Image Figure 5 RMSE.

Version	0	1	2	3	4
Strategy 3	83,10	71,76	58,17	38,03	13,84
Strategy 4	82,51	70,61	55,29	34,14	0,00

The error using the strategy 3 is greater than the error obtained when others strategies are used. Moreover, strategy 3 does not achieve a perfect reconstruction of the image at high resolution, unlike the rest of strategies.

This behavior is due to the fact that strategy 3 has used all image data in the analysis process, but only the transmitted tile coefficients have been used in the synthesis process, when also the neighbor data would be needed. These visual artifacts are extended in each synthesis process of the wavelet transform, causing an imperfect reconstruction of the complete image.

As a result, we can conclude that strategy 3 is not valid to be used for a terrain visualization application, due to the fact that visual artifacts will appear, resulting in a low quality terrain visualization.

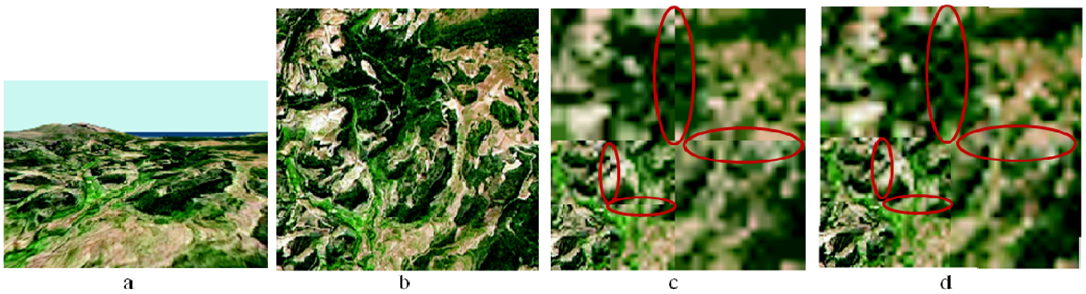


Figure 5: Visual artifacts image examples.

4.2 Lossless Compression Ratio

Terrain data size is an important factor, since it affects the amount of storage required, the bandwidth and the time required to transmit the data.

In order to analyze the compression rate that each compression scheme can reach, a set of different terrain images have been compressed using different tile sizes. Some examples of these images are shown in Figure 6.

In order to measure the compression rate, we divide the size of the uncompressed image at full resolution by the size of the compressed image ready to generate the tiled pyramid.

Table 2 shows a representative example of the compression ratio achieved for the different strategies when applied to the Figure 6 images using a tile size of 128 pixels. The size of these images goes from 2048x2048 till 16384x16384 pixels.

Figure 6: Four images used for compression test.

Table 2 shows that compression ratios provided by strategies 3 and 4 are equal, and better than those achieved by strategies 1 and 2. This is due to the fact that strategy 1 has to transmit different images for each level of resolution of the tiled pyramid, and the compressed image size will be not only the high level resolution image compressed size, but the addition of the size of each different resolution image. On other hand, strategy 2 treats each tile like an isolated image, thus limiting the amount of data available for the compression algorithm.

As a result, we can conclude that strategy 4 scheme provide the best compression ratio without producing visual artifact.

Table 2: Compression ratio for Figure 6 images using the four strategies.

	Image A	Image B	Image C	Image D
Strat. 1	1,67	1,78	1,68	2,36
Strat. 2	2,37	2,52	2,34	3,45
Strat. 3	2,41	2,56	2,37	3,55
Strat. 4	2,41	2,56	2,37	3,55

4.3 Lossy Compression Root Mean Square Error (RMSE)

Lossy compression introduces errors in each analysis step of the wavelet transform, degrading the reconstructed image at each reconstruction step. Nevertheless, this type of compression can be useful to reduce both the data size and the transmission time.

In order to study which compression scheme provides higher visual quality when using lossy compression, a set of images have been compressed using different bit rates. These images have been decompressed using all the information of each level of the tiled pyramid. The RMSE with respect to the original image has been measured.

Table 3 shows the lossy compression results in a quantitatively way. It shows the RMSE value obtained for the different strategies using different compression ratios for the image Figure 6-C. The image size is 2048x2048 pixels, using a tile size of 128x128 pixels (except for strategy 3, where the tiling process was not applied).

Table 3 shows that strategies 3 and 4 obtain image reconstructions of similar quality (and better than the strategies 1 and 2), although strategy 4 applies a tiling process and no tiles have been used for strategy 3.

The reason for this behavior is that strategy 1 repeats the information that has to transmit (the bit rate is measured taking into account all the different resolution images inside de tiling pyramid), so the data size is higher than the other strategies.

Table 3: RMSE – Lossy compression.

bpp	Strat. 1 RMSE	Strat. 2 RMSE	Strat.3 RMSE	Strat. 4 RMSE
0,05	30,28	35,80	27,99	28,22
0,10	25,33	27,52	22,83	23,03
0,15	21,89	22,82	19,73	19,95
0,25	17,67	17,47	15,05	15,26
1,00	7,54	6,72	5,98	6,03
2,00	4,04	3,39	3,02	3,07
3,00	2,58	2,09	1,88	1,91
4,00	1,88	1,49	1,38	1,40

Regarding the strategy 2, each tile is treated like an isolated image, causing a lower image quality and block effect. This block effect appears when a low compression ratio is used (for example 0.05 bpp).

Table 3 also shows that strategy 1 is better than strategy 2 for lower values of bpp, but it is worst for higher values of bpp. This is due to the fact that strategy 2 suffers from a smaller block effect as bpp is increased.

As a result, we can conclude that the proposed scheme results in the best performance providing similar lossy compression rates than strategy 3, although it does not provide visual artifacts.

5 CONCLUSIONS

In this paper, we have proposed a new compression scheme for terrain data to be used in remote terrain visualization systems, performing a comparative study with other three different strategies that can be used in terrain visualization applications.

The performance evaluation results show that the proposed scheme:

- Reuses previous information transmitted, reducing the data to be transmitted.
- It obtains a good compress ratio and visual quality.
- It can reconstruct terrain regions in an independent way, avoiding visual artifacts in the borders of these regions.
- It suits the tiled pyramid usually used to organize terrain data.

Meanwhile, strategy 1 does not reuse previous information transmitted, so it needs to transmit more data than the other strategies. Strategy 2 obtains a lower compress ratio and visual quality than the other strategies, and strategy 3 produces visual artifacts at the region borders when these regions are reconstructed in an independent way.

These results show that the proposal scheme can significantly improve the performance of remote terrain visualization systems.

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