Hybrid Scheme with Triangulations for Transform Coding

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Abstract. *Our approach to image region approximation offers a complete scheme consisting of several steps. We separate the encoding of region boundaries from the texture description. The original image is first segmented using an unsupervised segmentation method for color-texture regions. Following polygonal approximation of created regions causes the degradation of region boundaries. The triangulation is then applied to polygons and either all short edges, or all small triangles are filtered out from the triangular mesh. This results in new smaller regions. The encoding and decoding of polygons and triangles is very efficient, because we need to store only the vertices. For texture approximation we use 2D shape independent orthogonal transforms (e.g. DCT II). The texture is encoded with a code similar to JPEG arithmetic code. The encoding scheme proposed in this paper is much faster than latest approaches with polygonal approximation. We present the two triangulation algorithms – constrained greedy (CGT) and constrained Delaunay triangulation (CDT). Both CGT and CDT provide similar results.*

Keywords

Triangulation, polygonal approximation, texture approximation, orthogonal transforms, image compression.

1. Introduction

Lately, great concern in image processing is devoted to region oriented methods. Region oriented image representation offers several advantages over block-oriented approach, e.g. adaptation to the local image characteristics. New algorithms are necessary for image coding if we work on arbitrarily shaped image regions (segments), instead of on rectangular blocks. The original approach to the coding of arbitrarily shaped image segments based on a generalized orthogonal transform was discussed in [1]. The application scheme with iterative cosine transform is proposed in [2].

In [3] we presented a new approach to the region approximation with shape independent transforms using different number of basis functions for each segment. This principle is based on the JPEG scheme, where because of the varying number of basis functions, end-of-block information must be placed into the data stream after each segment. To partition the image we used an unsupervised segmentation method for color-texture regions [4]. After applying the polygonal approximation of region boundaries, the region homogeneity could corrupt and an unwanted ripple of the image could occur. Also the following iterative region approximation was too slow, it took several hours. To solve both problems we proposed the division of polygons into smaller regions using the constrained greedy triangulation [5]. In both encoder and decoder the same triangulation algorithm is implemented. Thus we do not need to store or transmit any additive information about the triangles.

In this paper we present a brief comparison between using the constrained greedy triangulation (CGT) and using the constrained Delaunay triangulation (CDT) for the following shape independent transform coding. Moreover, we propose to filter out all short edges or all small triangles from the triangular mesh to ensure the lower bit rate. We will show how the choice of triangulation algorithm and the choice of the following mesh filtration influence the encoding speed and the quality of decoded image.

2. Triangulation of Polygons

There are two triangulation algorithms, which we tried to implement for the purpose of increasing the speed of shape independent transform coding – CGT and CDT.

Greedy triangulation adds one edge to the triangulation at a time and terminates after the required number of edges has been added. The number of edges in triangulation is given by the size of the point set and by the number of points in the convex hull [6]. The advantage of greedy triangulation is that it is easy to be modified to accept constrained edges – the edges that the user needs to include into the triangulation. These edges are typically the edges of the prescribed non-convex area boundaries. In our case, each segment boundary element (a line between two adjacent vertices of a polygon) is the constrained edge. Such edges are simply accepted at the beginning of the triangulation process; therefore, no later accepted edge can intersect them.

A Delaunay triangulation of a point set is a triangulation, whose vertices are the point set, having the property that no point in the point set falls in the interior of the circumcircle (circle that passes through all three vertices) of any triangle in the triangulation [7]. A Planar Straight Line Graph (PSLG) is a collection of points and segments. Segments are simply constrained edges, whose endpoints are points in the PSLG. A constrained Delaunay triangulation of a PSLG is similar to a Delaunay triangulation, but each PSLG segment is present as a single edge in the triangulation. A constrained Delaunay triangulation is not truly a Delaunay triangulation.

3. Filtration of Triangular Mesh

The triangulation obtained either by CGT, or by CDT includes usually several hundreds of triangles (see experimental results), many of them are very small. Therefore it is very useful to filter out the smallest triangles. They cause higher bit rate after encoding the image at given approximation quality requirement and they have no essential effect on subjective image quality after decoding the image.

There are several possibilities, how to filter the triangular mesh. We can remove all resulting edges that are shorter than a given value and that are not belonging to the former region boundary. Edges on region boundaries cannot be omitted. In fact, removing one edge means joining two neighboring regions. We can also remove all triangles that can be circumscribed by a square of a given size. Removing the triangle means removing all its edges that are not belonging to the former region boundary. This usually results in joining several neighboring regions at once. Alternatively, we can remove all triangles, whose area is smaller than a given value.

4. Texture Approximation and Final Encoding

The texture inside each region is approximated iteratively using basis functions of 2D shape independent orthogonal transform (e.g. discrete cosine transform II, [2]). Unlike previous method, in our approach the number of basis functions is derived from the approximation quality requirement. The approximation comes up to PSNR of 40-50 dB for each segment. There is a possibility to interactively approve the quality of approximation and to use more exact approximation, if necessary. The results are normalized for human visual system with respect to the spectral elements, which are most important for human vision. Then the coefficients are linearly quantized. It results in an optimal number of basis functions for each region and causes a decrease of the final PSNR of encoded image. The last step of the process is the binary arithmetic code of the quantized basis functions, very similar to the JPEG arithmetic code.

The polygonal approximation of boundaries supports bit rate reduction, because there is no need to encode all directions between the endpoints of a boundary segment. Creating the line between two points of a boundary segment is based on Bresenham algorithm. The boundaries are encoded using the modified Huffman code. As mentioned above, in both encoder and decoder these boundaries are triangulated according to the same triangulation algorithm.

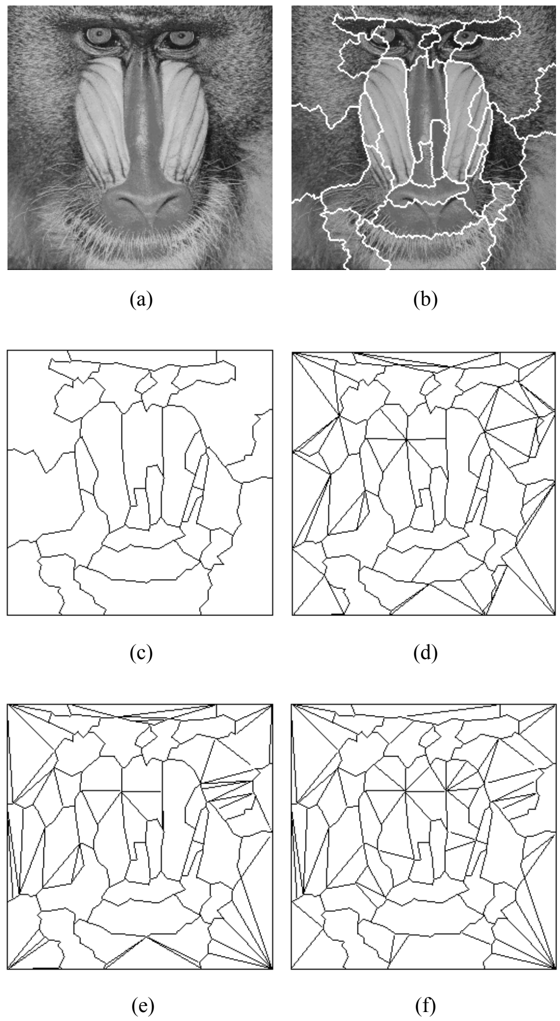


Fig. 1. Image baboon: a) original, b) segmented into 30 shapes, c) polygonal approximation, d) CGT and filtration of edges (81 regions), e) CDT and filtration of triangles (80 regions), f) CDT and filtration of triangles (85 regions).

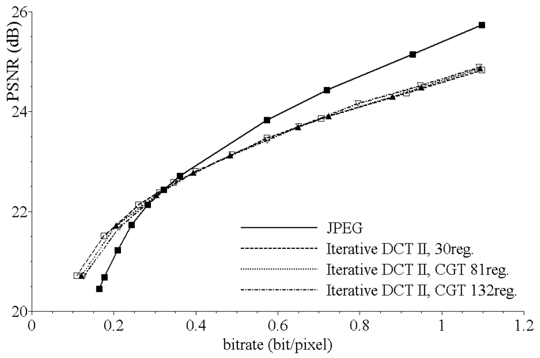
5. Experimental Results

The results of proposed approach are illustrated in figures and compared with conventional coders. Fig. 1a represents the original image of baboon with 256x256 pixels and 256 gray levels. Fig. 1b shows original image segmented into 30 regions, polygonal approximation of boundaries is portrayed in Fig. 1c. Fig. 1d – 1f represent image regions after triangulation and filtration:

- CGT with filtration of edges shorter than 26 pixels (81 regions),
- CDT with filtration of triangles that can be circumscribed by the square of size 36×36 pixels (80 regions),
- CDT with filtration of triangles, whose area is smaller than 200 (85 regions).

The above mentioned marginal values were estimated in order to achieve approximately the same number of regions by each method. For a comparison, the whole triangular mesh after CDT contained 493 triangles.

With DCT II texture approximation we obtained better qualitative results than with other texture approximations at the same bit rate. Therefore only the results for DCT II texture approximation are portrayed. Fig. 2 shows the diagrams of PSNR performance after decoding the image for various triangulations and filtrations of edges or triangles compared with those for conventional coders. As you can see, the curves for various triangulations and filtrations almost overlap. Lightly lower bit rate we can achieve when the triangulation has smaller number of regions.



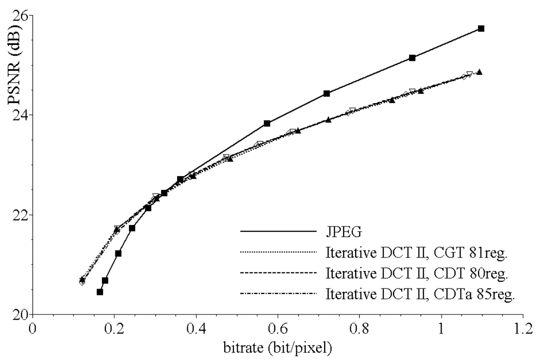
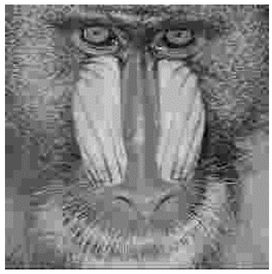
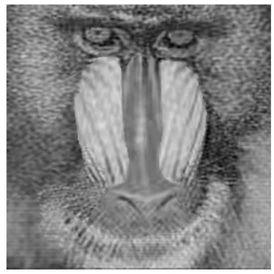


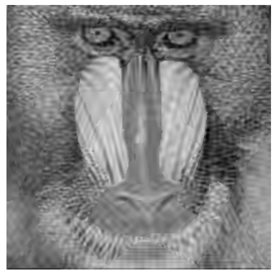
Fig. 2. Diagrams of PSNR performance after decoding the image for various triangulations and filtrations of edges or triangles. Compared with JPEG encoder (Corel PHOTO PAINT 9) and polygonal approximation.

Finally, Figures 3a – 3e represent the decoded image belonging to JPEG and region maps in Figures 1c – 1f respectively. All these images were coded at approximately 0.3 bit/pixel, slightly below the bit rate where all methods including JPEG succeeded the same value of the objective criterion (PSNR – see Fig. 2).


(a)


(b)


(c)


(d)


(e)

Fig. 3. Decoded images: a) JPEG approach (0.322 bit/pixel, PSNR 22.44dB), b) polygonal approximation of 30 regions (0.346 bit/pixel, PSNR 22.59dB), c) CGT and filtration of edges into 81 regions (0.303 bit/pixel, PSNR 22.33dB), d) CDT and filtration of triangles into 80 regions (0.300 bit/pixel, PSNR 22.36dB), e) CDT and filtration of triangles into 85 regions (0.297 bit/pixel, PSNR 22.32dB).

Tab. 1 illustrates the number of multiplications that occur while approximating the textures with DCT II transform up to the given approximation quality requirement (PSNR). The numbers in the table and decoded images in Figures 3a – 3e clearly explain that the usage of triangulation and filtration has not any important influence to the image quality, but it essentially increases the speed of encoding. The more regions after triangulation and filtration we have, the faster the texture approximation executes. However, the bigger number of regions causes the increase of the final bit rate. Therefore, some compromise should be chosen between the bit rate and the encoding speed.

6. Conclusion

The proposed method is sensitive to the quality of segmentation, number of regions, their sizes and depth of the approximation. Big size of the region increases the encoding time rapidly. For greater number of regions the method is not very efficient with respect to the bit rate. Boundary degradation has a very small effect on the quality of the resulting image, but it is very important for increasing the code efficiency. After the segmentation and polygonal approximation, further triangulation and filtration has almost no effect on the image quality. However, the encoding time is several times shorter than it is by using only polygonal approximation.

The computational time used for triangulation is much smaller than the time spent with region approximation using shape independent orthogonal transforms. Therefore, the time differences between CGT and CDT algorithms can be ignored. The choice of triangulation algorithm and the choice of the following mesh filtration have almost no effect on the encoding speed and on the quality of decoded image. Both presented triangulation methods, CGT and CDT, provide similar results.

texture approximation up to PSNR of	22dB	50dB
polygonal approximation 30 regions	650 903 104	34 995 961 856
CGT and filtration 81 regions	404 998 560	15 957 511 168
CGT and filtration 132 regions	210 774 048	8 661 553 152

Tab. 1. Number of multiplications during the DCT II texture approximation of all regions up to the given PSNR. Only the CGT with two different filtrations of short edges is here compared with the polygonal approximation without further triangulation. The CDT with filtration of small triangles results in values similar to CGT while using approximately the same number of regions.

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