GEOMETRIC AND TOPOLOGICAL LOSSY COMPRESSION OF DENSE RANGE IMAGES

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ABSTRACT

This paper presents a technique for lossy compression of dense range images. Two separate compression schemes are applied. The first scheme (*geometric compression*) reduces redundant geometric information by generating an adaptive 3D triangular mesh that approximates the shapes present in the original range image. Geometric compression is used for obtaining an efficient representation of the range image that allows further processing. The second compression scheme (*topological compression*) encodes the connectivity information contained in the triangular mesh. Topological compression is used for generating a compact representation suitable to be stored or transmitted. Both compression schemes avoid costly iterative optimization algorithms. Results with real range images are presented.

1. INTRODUCTION

Range images are gaining popularity in computer vision since they allow the efficient acquisition of 3D information. They are two-dimensional arrays of pixels, where each pixel represents the distance from a point that lies on the surface of a 3D object to a virtual plane referred to the range sensor utilized to acquire the image.

Much effort has been devoted to the development of algorithms for compressing intensity images. However, little attention has been payed to the development of techniques for compressing range images. At first glance, it appears that conventional image compression techniques can be applied to range images. A peculiarity of range images, though, is that the depth of the pixels is usually 16 bits. Unfortunately, most of the available image compression software handles 8 (monochrome) and 24 (true-color) bits per pixel, although in the latter case, the three color planes are processed separately. Therefore, in practice, the widely-used image compression tools are not applied to range images, and file compression utilities (e.g., *gzip*, *compress*) are commonly utilized. The problem with the latter is that they do not take into account geometric considerations, but more general data compression principles based on pattern matching, leading thus to low compression ratios.

Two approaches for compressing range images are considered in this work: geometric compression and topological compression. *Geometric compression* seeks the reduction of redundant geometric information by generating a representation with fewer data points than the original range image. Geometric representations are advantageous for speeding up further processing algorithms (e.g., segmentation [1], recognition, object modelling [2]). Triangular meshes are the representation commonly utilized for geometric compression, since they can efficiently adapt to intricate shapes. *Topological compression* seeks the reduction of information necessary to store geometric representations such as triangular meshes. Both compression techniques are complementary, since the representations generated through geometric compression can be further compressed topologically.

Many techniques for geometric compression have been proposed in the literature (e.g., [3][4][5]). These techniques apply costly iterative optimization algorithms that may make their application to systems with real-time constraints difficult. A fast geometric compression algorithm for generating triangular meshes from range images,

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avoiding optimization techniques was proposed in [6], but its randomized nature may be disadvantageous for some applications. Alternatively, an efficient, non-randomized technique for generating triangular meshes from range images without optimization was proposed in [8]. On the other hand, topological compression is a relatively recent issue with not much work done, which is being mainly applied to the compression of VRML files (e.g., [9]).

This paper studies the compression characteristics of the approximation technique previously presented in [8] and also the benefits of applying topological compression to the triangular meshes generated with it. It is shown that the best compression ratios are obtained with the combination of both techniques.

Section 2 summarizes the geometric and topological compression techniques utilized in this work. Section 3 presents experimental results with real range images. Finally, conclusions are given in section 4.

2. GEOMETRIC AND TOPOLOGICAL COMPRESSION

This paper proposes the combined utilization of two techniques for compressing range images. The first technique approximates the original range image with an adaptive triangular mesh containing a fraction of the points that constitute the given image. This mesh adapts to the shapes present in the range image by concentrating points in high curvature areas and dispersing over low variation regions. That mesh is then topologically compressed through a technique that codifies the connectivity of the triangles contained in the mesh. Both techniques are summarized below.

2.1. Geometric compression

The goal of geometric compression is the generation of an adaptive triangular mesh that approximates the surfaces represented in a given range image. Those meshes are generated in two steps. In the first step, an adaptive quadrilateral mesh approximating the original range image is obtained with no optimization. In the second step, each quadrilateral cell is divided into two triangles through a data-dependent triangulation algorithm.

2.1.1. Adaptive quadrilateral mesh generation

The generation of an adaptive quadrilateral mesh consists of three steps summarized below. A complete description is given in [7].

First, an estimation of curvature is computed for every pixel of the given range image, obtaining a *curvature image*. Then, both the given range image and its associated curvature image are partitioned into a user-defined number of rectangular tiles. Each tile is considered to be a small range image upon which further processing is applied. Then, the following steps are independently applied to each tile. First, a predefined number of pixels is chosen for each row of every tile according to the previously computed curvature. After the previous sampling, a set of *vertical curves* is obtained, Fig. 1(*top-right*). Then, each curve is adaptively sampled by following a similar principle. Thus, a predefined set of pixels is obtained for every tile, in such a way that they are distributed according to the curvatures present in the tile. The points tend to concentrate in high curvature regions and to disperse in low variation areas. This process is done without applying iterative optimization.

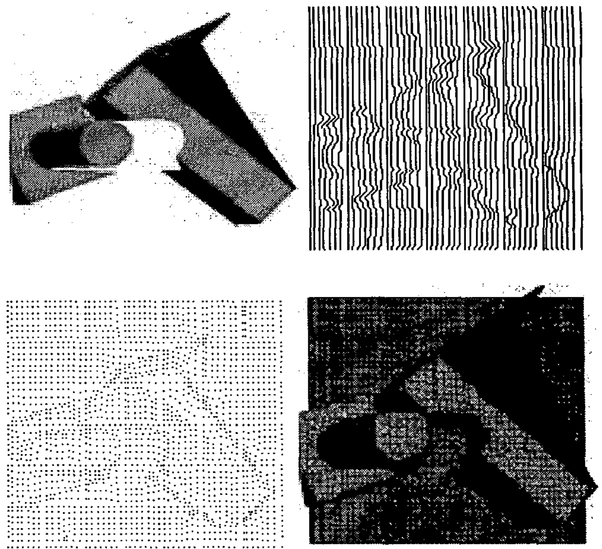

Figure 1. (*top-left*) Original range image (188x208). (*top-right*) Vertical curves computed in an intermediate stage. (*bottom-left*) Adaptive sampling with 43x50 points. (*bottom-right*) Adaptive triangular mesh.

Fig. 1(*top-left*) shows a real range image with 39,104 points. The set of 2,150 points chosen by the adaptive sampling technique is shown in Fig. 1(*bottom-left*). The final adaptive quadrilateral mesh is trivially computed by joining all those points horizontally and vertically.

2.1.2. Data-dependent triangulation

The outcome of the previous stage is a quadrilateral mesh. Each quadrilateral cell is then divided into two triangles by choosing the diagonal that best agrees with the discontinuities present in the cell. This is done by adding the gradient vectors corresponding to the range image pixels traversed by each diagonal. Two resultant gradient vectors

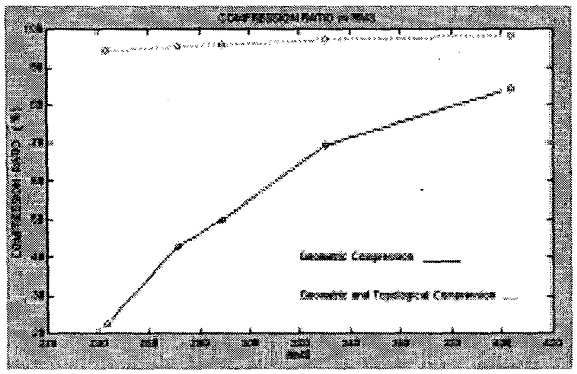

Figure 2. Compression ratio versus root mean square approximation error (RMS) for the range image shown in Fig. 1, considering different mesh resolutions

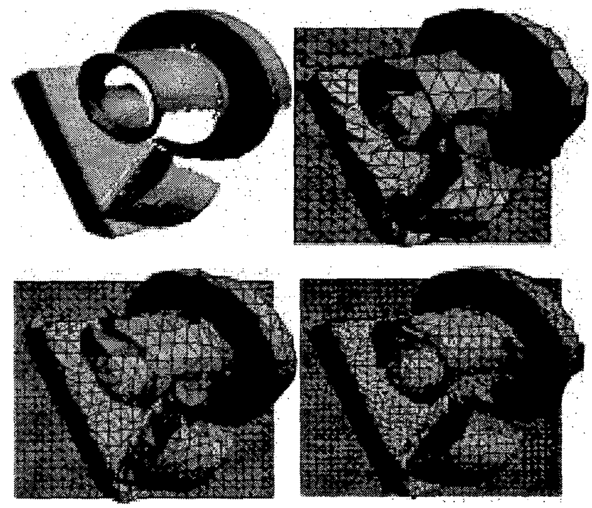

Figure 3. (*1. top-left*) Original range image (28,182 points). (*2. top-right*) Adaptive triangular mesh with 441 points. (*3. bottom-left*) Adaptive triangular mesh with 725 points. (*4. bottom-right*) Adaptive triangular mesh with 1,296 points.

are obtained (one for each diagonal). The largest vector is then chosen as a representative of the orientation of the discontinuities present in the cell. The diagonal which is most perpendicular to this gradient vector is chosen to split the cell. Fig. 1(*bottom-right*) shows in wireframe the adaptive triangular mesh obtained for the range image shown in Fig. 1(*top-left*). A more detailed explanation about this data-dependent triangulation algorithm can be found in [8].

2.2. Topological compression

The goal of topological compression is the reduction of the amount of information necessary to represent a triangular mesh. In this work, a public implementation of an algorithm presented in [9] has been utilized. This technique codifies a triangular mesh with two spanning trees. The first spanning tree contains all the points of the given mesh. Instead of storing the positions of each point, the offsets between the 3D positions of adjacent points in the tree are saved. To encode the connectivity information, a spanning tree of all the triangles of the mesh is obtained. The position of each triangle with respect to one of its neighbors can then be codified with two bits.

3. EXPERIMENTAL RESULTS

Different range images have been processed by using the aforementioned geometric and topological compression techniques. Fig. 2 shows the compression ratios obtained by applying both the geometric and the geometric plus topological compression algorithms to the range image shown in Fig. 1, whose 39,104 points are stored in 78,208 bytes. Different RMS errors are obtained by modifying the number of points sampled during the quadrilateral mesh generation stage (section 2.1.1).

The triangular meshes generated by the geometric compression algorithm described in section 2.1 are stored in a binary representation that keeps a vector of point positions in 3D space, and, for each point, the list of indices corresponding to its adjacent neighbors. The result of the topological compression algorithm is a VRML compressed binary file [9]. The sizes of those representations have been compared to the size of the original range image file (78,208 bytes). The result of applying geometric plus topological compression to the range image shown in Fig. 1 leads to compression ratios above 95% (20:1).

Fig. 3 and Fig. 4 show examples of the application of the geometric compression technique to two other real range images, considering different approximation errors. The compression ratios, root mean square errors and maximum height variations, considering the application of both geometric and geometric plus topological compressions are shown in Table 1.

If a file compression tool (*gzip*) is utilized to compress the same range images, a compression ratio of 3:1 is obtained for both examples, although, in that case, the compression is lossless. If topological compression is directly applied to the triangular meshes that contain all the points of the original range images, without prior geometric compression, ratios of 2:1 and 3:1 are respectively

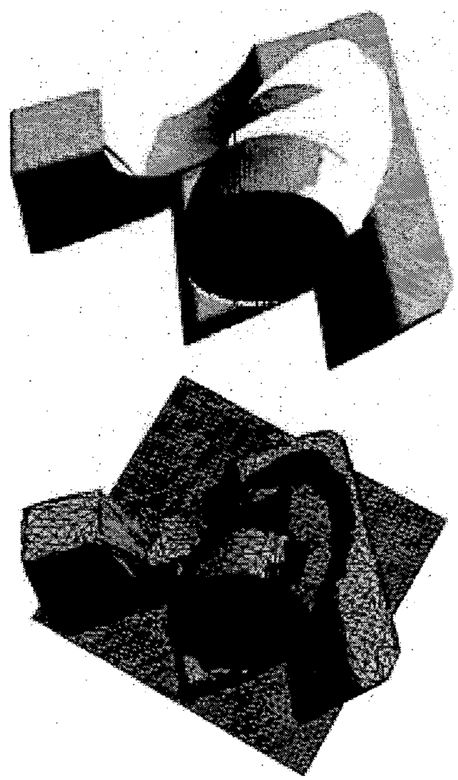

Figure 4. (*top*) Original range image (36,839 points). (*bottom*) Adaptive triangular mesh with 2,116 points.

Fig.	Compression Ratio Geom	Geom + Topo	RMS Error	Max ΔZ
3.2	7:1	55:1	361.9	3,652
3.3	4:1	43:1	352.4	3,652
3.4	2:1	27:1	280.8	3,652
4	2:1	24:1	289.4	4,459

Table 1: Compression ratios versus Root Mean Square error for the examples shown in Fig. 3 and Fig. 4.

obtained. Thus the application of geometric plus topological lossy compression produces the best results.

4. CONCLUSIONS

This paper studies the problem of range image compression by using two compression techniques applied consecutively: geometric compression followed by topological compression.

The geometric compression technique is responsible for the removal of redundant information contained in the original range image. Thus, the data points arranged in the original range image as a regular array are structured as an adaptive triangular mesh [8]. This triangular mesh preserves the same surface shapes with fewer data points. For example, large planar areas, which in the original range image may occupy thousands of pixels, can be represented by a few triangles. Then, this triangular mesh is codified through a topological compression technique [9]. This latter stage is responsible for encoding the information associated with the vertices and triangles of the mesh, by referring them to the information associated with their adjacent neighbors.

Range image compression is a relatively new research area with much work to do. Further work will consist of the automatic determination of the different parameters required by the geometric compression stage, taking user-defined approximation errors into account.

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