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Progressive compression and transmission of PointTexture images ☆

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Abstract

A progressive compression and transmission algorithm for PointTexture 3-D images is proposed in this work. The proposed algorithm represents a PointTexture image hierarchically using an octree. The geometry information in octree nodes is encoded by the predictive partial matching (PPM) method, while the color information is encoded using the discrete cosine transform (DCT). The encoder achieves the progressive transmission of the 3-D image by transmitting the octree nodes in a top-down manner. We develop two transmission schemes, based on the rate–distortion (R–D) optimization and the view-dependent optimization respectively, to maximize the image quality subject to a given bit budget. Extensive simulation results demonstrate that the proposed algorithm is an efficient method for progressive transmission of 3-D data.

Keywords: PointTexture; 3D image coding; Rate–distortion optimization; View-dependent optimization; MPEG-4

1. Introduction

Three-dimensional (3-D) data are widely used in various applications, such as virtual reality, video game and animation. Among various representation tools, the mesh representation has been a dominant method to represent 3-D data. However, photo-realistic 3-D meshes require a huge amount of storage space in general, and their distribution over digital communication channels is limited by the available bandwidth. Thus, it has drawn a lot of attention to compress 3-D mesh models to reduce the storage requirement and the transmission bandwidth [1,2].

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Attempts have been made to develop alternative 3-D representation methods also, which are more efficient than the mesh representation. In the volume representation, a model is represented by a 3-D array of voxels [3], instead of a collection of triangles. A voxel is a cubic volume element, which is the 3-D counterpart of a pixel in two-dimensional (2-D) raster graphics. To represent geometry data, a binary number can be assigned to each voxel: '1' voxels represent opaque regions, while '0' voxels represent transparent background. Kim and Lee [4] proposed the pattern code representation (PCR) algorithm, which encodes geometry data into a series of pattern codes. It can provide a coding gain by exploiting the high correlation in adjacent pattern codes. It was later extended to the progressive scheme in [5].

Levoy and Whitted [6] first proposed points as rendering primitives. To render continuous images from points, several algorithms have been proposed to remove gaps in the rendered images [7,8]. Surfels [9] and QSplat [10] are two recent schemes for 3-D data representation using point primitives. In [9], a 3-D model is represented by regularly sampled surface elements, which contain depth, color, and normal properties. On the other hand, QSplat [10] represents a model using a hierarchical set of spheres. Zwicker et al. [11] proposed a point-based surface editing algorithm, called Pointshop 3D. In [12], an octree-based approach was proposed to represent point data hierarchically and render them efficiently. Also, several compression algorithms have been proposed to encode point data compactly [13–15].

Depth image-based representation (DIBR) is a new approach to represent and render 3-D objects with complex geometries [16]. It is related to both the volume representation and the point representation. Instead of representing objects with polygonal meshes, DIBR represents a 3-D object with a set of reference images covering its visible surface. Each reference image comes with a depth map, which is an array of distances from the pixels in the image plane to the object surface. Shade et al. [17] proposed a DIBR method, called layered depth image (LDI). An LDI has a single reference image, but its each pixel can represent multiple points along each line of sight. Chang et al. [18] investigated a hierarchical representation of 3-D objects based on the LDI method. Duan and Li [19] proposed an algorithm to compress LDIs. Their algorithm employs several 2-D image compression standards to encode color and depth data. Since LDI data are sparser than 2-D images, they proposed a data aggregation method to improve coding gain. The aggregation method, however, does not fully exploit the characteristics of 3-D surfaces and the resulting data may not exhibit sufficiently high correlation.

DIBR has been adopted into MPEG-4 Animation Framework eXtension (AFX) [16,20]. It has three formats: SimpleTexture, PointTexture, and OctreeImage. Among them, PointTexture is similar to LDI and has several advantages over the traditional mesh representation. For example, PointTexture can represent photo-realistic 3D objects without complex mesh structures. Also, its rendering complexity depends only on the image resolution, regardless of the object complexity. To render a PointTexture image, each point is simply drawn as a circular disk with its own color [16]. Thus, the rendering of PointTexture images is faster than that of triangular meshes in general. However, complex PointTexture images require a large amount of data and their compression should be performed efficiently. Although Duan and Li's algorithm [19] can be modified for the compression of PointTexture Images, it does not support progressive compression and transmission. To transmit 3-D objects over the Internet or wireless channels, it is desirable to develop progressive coding schemes, which can facilitate interactive 3-D model browsing and the adaptation of transmission bit rate.

In this work, we propose a novel algorithm to compress PointTexture images progressively. An octree structure is employed to represent PointTexture images hierarchically. The proposed algorithm encodes the geometry information in the octree nodes using the predictive partial matching (PPM) scheme [21], which employs preceding data as a context to exploit the correlation in 3-D shapes. Also, the proposed algorithm encodes the color information based on the discrete cosine transform (DCT). The proposed algorithm supports flexible transmission of PointTexture images. Specifically, we illustrate two progressive transmission schemes, based on the rate–distortion (R–D) optimization and the view-dependent optimization, respectively.

This paper is organized as follows. Section 2 briefly reviews the formats and data structures of DIBR. Section 3 describes the octree generation algorithm. Section 4 proposes the compression algorithm for node data, and Section 5 develops two adaptive transmission schemes for node data. Section 6 describes the decoding algorithm. Section 7 provides simulation results. Finally, conclusions are drawn in Section 8.