AN IMPROVED VISUALIZATION OF LiDAR DATA USING LEVEL OF DETAILS AND WEIGHTED COLOR MAPPING

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ABSTRACT

This paper proposes an improved approach for LiDAR data visualization in terms of rendering quality. The method uses adaptive point-scaling for dealing with variations in data densities, while the contrasts of rendered objects are improved with weighted color mapping. In the former case, points' distances from the observer are used to estimate their optimal rendering sizes. In the latter case, points are colored based on height attributes and increasing visual fidelity a point's color is weighted using that point's intensity information. Common image quality matrices, as well as conducted user study, confirm the improvements of the visualization.

1 INTRODUCTION

Visual analytics of remote sensing data are at the heart of numerous environmental studies. Scientific disciplines like geography [1], biology [2], and ecology [3], are increasingly relying on information gathered by advanced Earth observation systems. These are capable of capturing precise and high-resolution data from vast geographic areas within a short period of time. Light Detection and Ranging (LiDAR) technology in particular, has transformed the traditional approaches to monitoring the Earth's surface with its reliability, great accuracy, and high density of acquired point-clouds. Consequently, the specifics of LiDAR stimulate new visualization techniques capable of clearly exposing the objects contained within these datasets, while overcoming the issues of huge sizes and lack of topology that are inherent with LiDAR point-clouds. In this paper, a new approach to LiDAR data visualization is considered which exploits weighted color mapping for increasing visual contrasts between the contained features. The underlying concepts of the proposed approach are introduced in Section 2. Section 3 explains the proposed method. Discussion and the results are given in Section 4, while Section 5 concludes the paper.

2 RELATED WORK

The majority of real-time visualization techniques use hierarchical space subdivision for efficient scene representation. A method based on recursive data subdivision with a quadtree was presented by Lindstrom et al [4]. They used a hierarchy in which each depth of the tree corresponded to a certain detail level. Therefore, it was easy to combine different detail levels into final data representation. Their system also considered the roughness of the surface and used less details where the topography was smoother. Similar methods have also been developed using Delaunay triangulation for continuous surface Level of Details (LOD) [5].

The concept of using points as rendering primitives for representing an object has been introduced in the pioneering work by Levoy and Whitted [6]. Rusinkiewicz and Levoy [7] developed a point-based rendering system (PBS) named QSplat that was capable to interactively rendering surfaces with large numbers of points in real-time. Their solution was based on a multi-resolution hierarchically bounded sphere for LOD. Recently, Kovač and Žalik [8] developed a two-pass point-based rendering technique that uses elliptical weighed average filtering for solving problems relating to aliasing.

More sophisticated approaches are based on the Human Vision System (HVS) [9], where perceptual metrics like spatial frequency and visual acuity are used to determine visible differences between images. The Just Noticeable-Difference (JND) approach was presented by Cheng et al. [10]. JND uses a perceptual analysis for improving the results of geometric measures for identifying redundant data. A volume-rendering algorithm that follows the user's gaze and smoothly varies the display resolution has been developed by Levoy and Whitaker [11]. Gaze-contingency uses models of human spatial perception and can be applied to geographic data representation.

3 VISUALIZATION

Visualization of LiDAR data remains a difficult problem, where the main challenges are imposed by huge amounts of topologically unstructured data and variable data-density. Due to limited graphical memory, these datasets cannot be fully processed on graphical processing units (GPU), while data structuring and topology establishing (e.g. triangulation) are ineffective due to additional resources. Consequently, a more intuitive way for LiDAR point-cloud's visualization is to deal with each point as a separate display primitive. Although those implementations using such simple primitives [6] are fast and robust, they produce coarse images i.e. empty gaps between primitives where point densities are not sufficiently high. Therefore, it is necessary to find a balance between technical and perceptual abilities.

In the continuation, a new visualization architecture is described aimed at improving data perception, together with an efficient data organization for real-time rendering.

3.1 Data Management

The basis for fast and effective visualization of point-clouds is hierarchical space partitioning, where data are divided into smaller segments. Since LiDAR data can be considered as 2.5D, a quadtree data structure is applied for this purpose [12]. The quadtree root covers the whole area and its 4 children divide space into equal quadrants. Space subdivision is obtained by inserting point after point into the corresponding node of the quadtree. When a node contains a predetermined maximal number of points, space subdivision is performed by dividing the node into four subnodes and rearranging the content. The space partitioning is constructed during the pre-processing phase. The needed geometry is stored within the graphic memory using vertex buffer objects (VBO), which speeds up the rendering process. This also allows for the maintaining of only point indices and VBO references within the main memory. Rendering points are randomly sampled from the VBO.

3.2 Rendering

In order to achieve real-time visualization, it is necessary to reduce the number of display primitives for rendering. A frustum culling technique is applied on the space subdivision hierarchy to exclude subspaces being outside the viewing frustum. However, this is usually not enough for achieving real-time visualization, and visible points inside the viewing frustum also need to be considered for removal. For this purpose, additional LOD technique is applied for further simplifying the scene. LOD is realized by rendering detailed geometry when the subspace is close to the observer, and a coarser approximation when it is distant or occupies a small screen space. In this way, the rendering workload is significantly reduced. As described by Pečnik et al. [12], the optimal percentage of rendered points L_j for a subspace j can be defined as:

$$L_j = \frac{D_j \cdot (R-1)}{D} + 1 ,$$

where D_j is the distance between the observer and the center of subspace j, D is the average distance for all visible subspaces from the observer and R is the average percentage of rendered points. However, despite its advantages regarding performance LOD also has some significant drawbacks in terms of image quality. Optimizations for improved visual quality are described in the continuation.

Adaptive point-scaling

The main problem when reducing the graphic workload is the scarce density of points, leading to noticeable gaps between them [7]. In order to deal with this issue, a new approach to LOD is proposed here by considering both the sizes of the rendering points in addition to their quantity.

Determination of an adequate point size is of critical importance for avoiding visual gaps within as the image. An illusion of a continuous surface is created if the points are large enough to sufficiently overlap, see Figure 1. Therefore, a point's size is calculated according to the distance of the observer from the subspace. By considering spatial perception, point sizes should be inversely proportional to the distance from the observer, since subspaces further away from the observer occupy a smaller portion of the screen space. Consequently, they can be rendered using smaller points and vice versa. The point size S_j for each subspace is defined by

$$S_j = 1 + \lfloor L_j \cdot \rho \rfloor,$$

where ρ is the average points density of all subspaces.

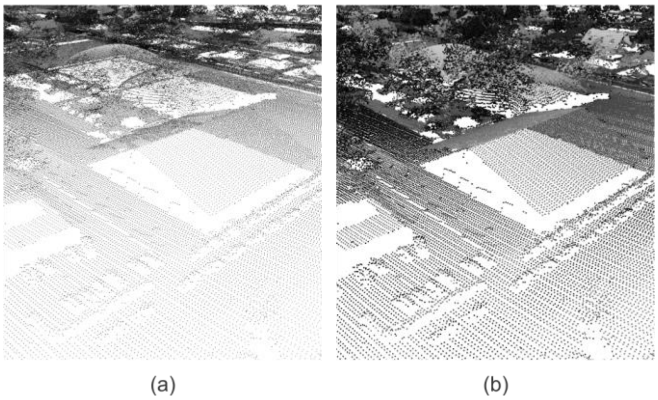

Figure 1: *LiDAR data visualization: rendering without optimization (a), rendering with adaptive points-scaling (b).*

Weighted color mapping

The colors of LiDAR points are typically derived at from the returned laser intensities or airborne image projected onto the point-cloud. These approaches are fine for general data visualization, whereas they fall short regarding the in-depth visual analytics of specific features as they cannot provide adequate contrasts between them. The main reasons for this are the low intensities of points beneath the vegetation and multiple points sharing the same colors, when images are projected on them. Here, we have focused on improving the contrast based on the heights of LiDAR points, i.e. height map visualization.

Typically a height map is visualized by mapping the grayscale pallet between the minimum and maximum height of the targeted data. This limits the visualization, since on most conventional display devices the grayscale pallet has an effective 8-bit range. Therefore LiDAR data can only be effectively visualized for a small height range before visual quantization takes place. In order to improve upon this, this method takes advantage of color perception and the point's returned laser intensities. Though color mapping is not a novel concept and is among other fields used extensively in cartography [13], but has a great impact on visual perception. Because there is no optimal general purpose color map, many application specific color maps exist. Firstly to generate the point's colors, color mappings are applied to the LiDAR points which are histogram equalized, with regard to their height attributes, ranging between 0 and 1. The equalized height value for point i is used to retrieve the color C_i from the color look-up table (CLUT). The equalization achieves a color merging of outlier points, which are typical in LiDAR data and cause severe extensions of mapping ranges, leading to suppressions of contrast between the majority of points. In this way, more color variety is given to those points with heights at the peaks of the probability density function. The CLUT used is a linear sampling through the HSV color model. The path used is defined by HSV points (200, 1, 1), (140, 1, 1), (60, 0.5, 1) and (30, 0, 1). Only unique 8-bit RGB colors are retained from the sampling process, producing an expanded color pallet, as seen in Figure 2, with over 765 unique colors i.e. over three times that of a grayscale map.

Figure 2: *Generated color mapping with sampling duplicates removed.*

In order to increase visual fidelity, each point's color C_i is weighted with the point's intensity, producing the final color $C_i^{'}$. The point intensities are also histogram equalized, values ranging between 0 and 1. Doing this restores visual cues about dataset structures while still preserving the height map.

4 RESULTS

The visual acuities on 4 different LiDAR datasets were compared according to different terrain-types. The image qualities were evaluated using two different Image Quality Assessments (IQA) algorithms based on Human Visual System (HVS). We calculated the Blind Image Quality Index (BIQI) [14] and Naturalness Image Quality Evaluator (NIQE) [15], on datasets that were rendered with and without both optimizations, separately. Smaller values of the metrics refer to better quality and vice versa. The rendered images can be seen in Figure 3.

The evaluation results are presented in Table 1. The proposed adaptive point-scaling improved the results in all datasets with regards to both IQA metrics. However, when comparing the visual acuities for weighted color mappings, this was found to be problematic since the method focused on height map visualization for which there is no true reference image, i.e. ground truth with which to objectively compare the methods' results. Existing methods such as BIQI and NIQE, which are blind image quality assessment (BIQA) methods, operate on grayscale images. Thus, the used BIQA methods are not appropriate for quantifying the method's image quality, since the RGB to grayscale conversion is subjective. A user survey with 18 participants aged 22 to 47 was conducted, where users were given a set of pair images, grayscale and color heightmaps, and were asked, which one was more suitable for estimating the heights of different objects within the images. Most responded positively to the color images, with a few notable comments. One participant noted that it was much easier to see similar height objects in the color images, due to the relief-like visual cues caused by the color mapping, while another participant was pleased with the improvements in color image when compared to darker regions in grayscale image. The increase in visual fidelity, when the intensity information was included in color mapping, was well accepted. While, with only CLUT many features are masked because contrasts between points are lower and participants perception of heights was worsened. At the time of survey, there were no known issues with participant's color perception, so it was not determined if weighted color mapping is suitable for color blind users.

5 CONCLUSION

This paper proposed a new method for efficient LiDAR data visualization based on LOD. Without reducing the computational efficiency of this approach, we have proposed two improvements on rendering quality by adaptive point sizing and contrast enhancement with weighted color mapping. As confirmed by objective as well as subjective evaluations, the proposed approach improves visual analytics by allowing users to clearly distinguish between rendered objects.

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Table 1: *IQA results of adaptive point-scaling and weighted color mapping optimizations.*

Dataset	BIQI			NIQE		
	no optimization	point-scaling	color mapping	no optimization	point-scaling	color mapping
Urban	101.26	75.84	99.02	13.27	9.49	13.71
Roundabout	69.73	65.33	64.87	15.36	12.26	15.11
Mountain	78.59	50.43	80.19	11.35	8.30	12.11
Flat	74.97	30.76	70.49	7.50	7.86	9.58

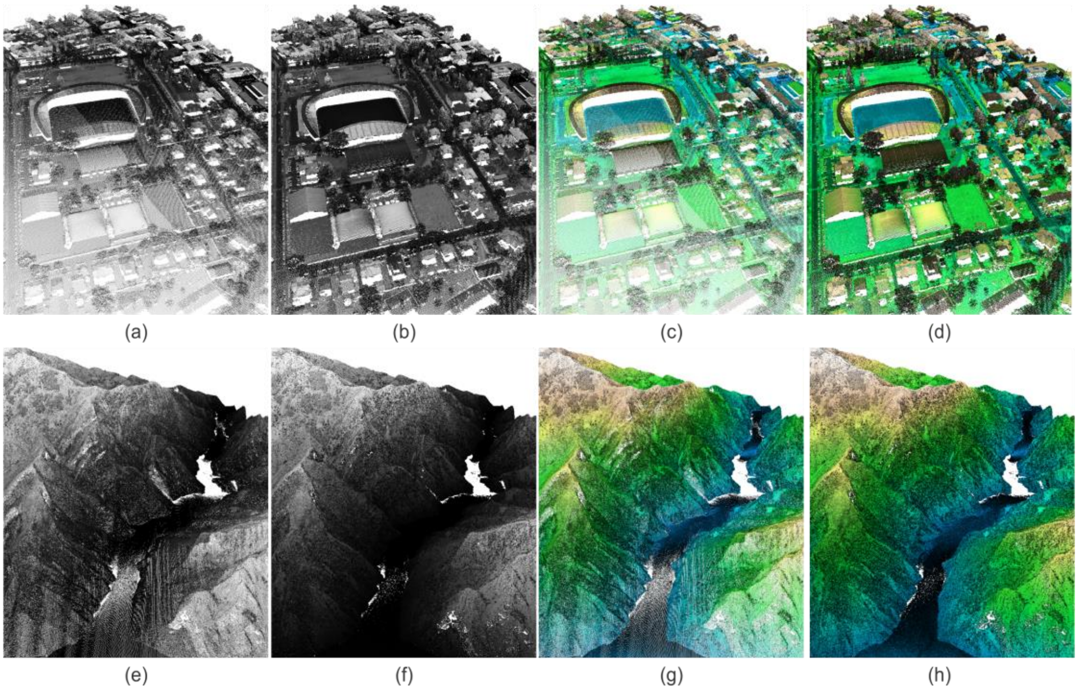

Figure 3: *Evaluation of improved visualization of LiDAR data: urban dataset without optimization (a), with adaptive point-scaling (b), with weighted color mapping (c), with adaptive point-scaling and weighted color mapping (d); mountain dataset without optimization (e), with adaptive point-scaling (f), with weighted color mapping (g), with adaptive point-scaling and weighted color mapping (h).*

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