PATCH-BASED TEXTURE RECONSTRUCTION FROM COLORED POINT CLOUD

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ABSTRACT

Base maps are required for outdoor applications. In unknown environments, laser scanning is a more adequate approach. However, in laser scanning, when there are large missing and occluded areas, it is not easy to generate complete base and floor maps automatically. Thus, we focused on an image inpainting for colored point cloud rendering. Our approach was aimed at improving the quality of a digital elevation model (DEM) and ortho images generated from colored point cloud data. Our inpainting procedure consisted of base patch extraction, matching point detection, and image reconstruction steps. These steps were iterated for the reconstruction of a natural image. We have developed an inpainting approach for colored DEM generation using a colored point cloud. Moreover, we conducted an experiment using a terrestrial laser scanner. Through our experiment, we have confirmed that our approach could reconstruct natural textures and colored DEM from colored point cloud data with missing areas.

1. INTRODUCTION

In construction information modeling (CIM), base maps and 3D data are required for managing processes of construction, maintenance, rehabilitation, and replacement. Online maps, such as Google Maps and OpenStreetMap, are useful for infrastructure inspection in urban areas. However, in rural areas and mountainous districts, the online maps are often insufficient for infrastructure inspection to recognize the details of natural features. Thus, base maps and 3D data should be prepared before the inspection. In an open-sky environment, aerial photogrammetry and structure from motion (SfM) using an unmanned aerial vehicle (UAV) is more effective than ground-based scanning. On the other hand, when environments include natural obstacles, such as trees, a terrestrial laser scanner is more effective than a UAV or a mobile mapping system (MMS). We expect that terrestrial laser scanning could generate a colored digital elevation model (DEM) from the acquired colored point cloud. However, when we acquire a point cloud around riversides which include many water surfaces, there will exit numerous missing points because of the laser reflection problems.

Moreover, floor maps and 3D data are also required in indoor navigation and building information modeling (BIM). We expected terrestrial laser scanners and indoor MMS to be adequate for colored point cloud acquisition in an indoor environment. However, missing areas and a nonuniform density of the point cloud would exist in point cloud acquisition. This issue causes transparent and near-far effects in point cloud visualization. Thus, we have developed a spatial interpolation based on point-based rendering to avoid these effects in the point cloud visualization and modeling (Nakagawa et al. 2011). Nevertheless, when large missing areas and occluded areas exist, the spatial interpolation approach is inefficient and ineffectual.

Therefore, we focused on a randomized algorithm to find approximate nearest-neighbor matches between image patches quickly for image inpainting (Barnes et al. 2009). The image inpainting aims to improve image quality with deletion works of scratches and unnecessary objects in an image and reconstruction works of the natural image. That is, scratches and unnecessary objects are replaced by other textures in the image. In manual works, these objects are replaced using an image retouching software such as Adobe Photoshop. The inpainting approach is an automated procedure for image retouches.

Our inpainting procedure consisted of three steps. The first step was base patch extraction. In conventional image inpainting, we select a polygon to input manually in an image to determine a missing area. On the other hand, in our approach, a base patch on the boundary of the missing area was extracted automatically in a colored point cloud (Oh et al. 2009). The second step was matching point detection. In this step, a reference patch was determined with a matching algorithm based on image matching from the colored point cloud. The third step was an image reconstruction. In this step, missing points in the base patch were reconstructed using points in the reference patch. These steps were iterated for reconstructing the natural image.

Our approach was aimed at improving the quality of the DEM and ortho images generated from the colored point cloud data. For our experiments, we selected a mountain stream as an outdoor environment. Through our experiment, we confirmed that our approach could reconstruct natural textures from colored point cloud data with missing areas.

2. METHODOLOGY

First, we prepared a colored DEM (an ortho image and DEM) from the colored point cloud data. Second, we estimated pixel values of missing and occluded areas in the colored DEM with our inpainting-based approach.

2.1 Colored DEM generation from point cloud

Colored DEM generation from a point cloud is described in Figure 1. When we use a terrestrial laser scanner at the ground surface, we can acquire points on feature surfaces from a sensor viewpoint. These points can be arranged along vertical lines with an arbitrary spatial resolution. When lower points in each vertical line are extracted, these latter points can be assumed as the ground surface. Therefore, these lower points can be used to generate a DEM. Additionally, when the acquired points have color information, an ortho image can be generated using the lower points.

In a conventional inpainting approach, missing pixels in a colored DEM are selected manually. Thus, the conventional inpainting procedure requires only an image. However, we prepared the DEM with an ortho image (i.e. colored DEM) to automate the missing pixel selection. Moreover, the colored DEM could be used to reconstruct the enhanced point cloud after the inpainting.

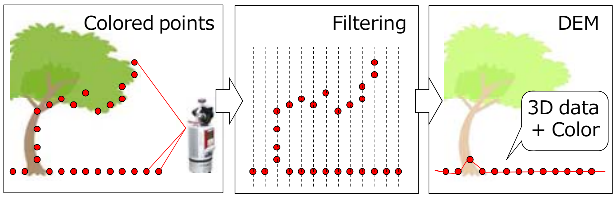

Fig. 1 Colored DEM generation

2.2 Inpainting procedure

An overview of the inpainting procedure is described in three steps (Figure 2). The red areas in this figure indicate missing pixels in a colored DEM. The first step was a base patch extraction. In this step, a base patch (for example, 5 × 5 pixels) is selected from the colored DEM. The center point of the base patch should be on the boundaries of missing pixels (regions) in the colored DEM. The second step was matching point detection. In this step, a reference patch that existed within an arbitrary search range is detected with image matching procedure (for example, SAD matching). Moreover, missing pixels in the base patch are masked in the matching procedure. The third step was image reconstruction. In this step, pixel values in the reference patch were copied to missing pixels in the base patch or in corresponding areas in the colored DEM. These steps were iterated to fill all missing areas in the colored DEM. The details of the processing flow of the inpainting procedure are described in Figure 3.

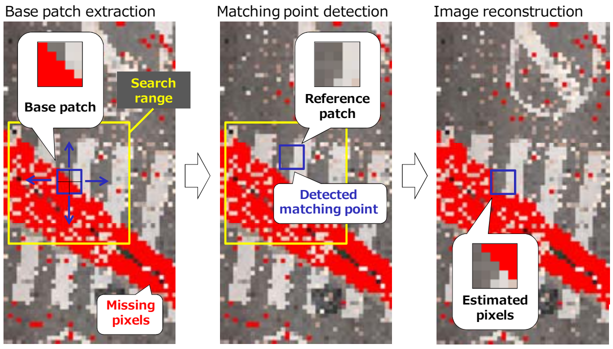

Fig. 2 Overview of our proposed approach

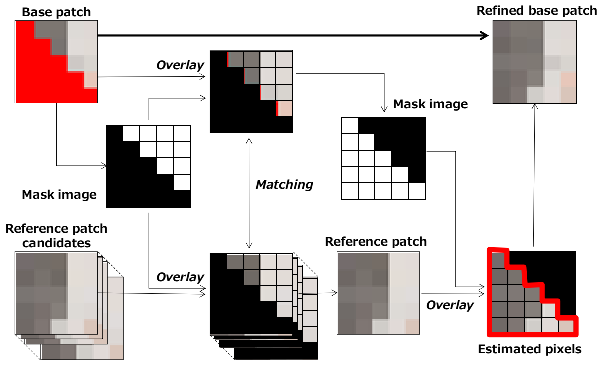

Fig. 3 Process flow of the inpainting procedure

3. EXPERIMENT

A mountain stream and a sediment-retarding basin in Fukushima city was selected as our outdoor study area. The study area consisted of dikes, bridges, debris barriers, and water surfaces. A water surface is one of the more difficult objects for laser scanning and photogrammetry. However, water splashes are sometimes measured with a laser scanner, and we tried to reconstruct the water surface using these measured data. We used the Riegl VZ-400 in our terrestrial laser scanning. We acquired 114 million colored points (Figure 4) from 7 points.

Fig. 4 Point cloud acquired with terrestrial laser scanner

4. RESULT

We generated a colored DEM with a ground resolution of 5 cm from the point cloud. Several missing areas were present in the DEM because of laser reflection problems (Figure 5). Thus, we applied the inpainting procedure to the colored DEM from the laser scanning data. Linear and cubic interpolations and inpainting were applied to the colored DEM.

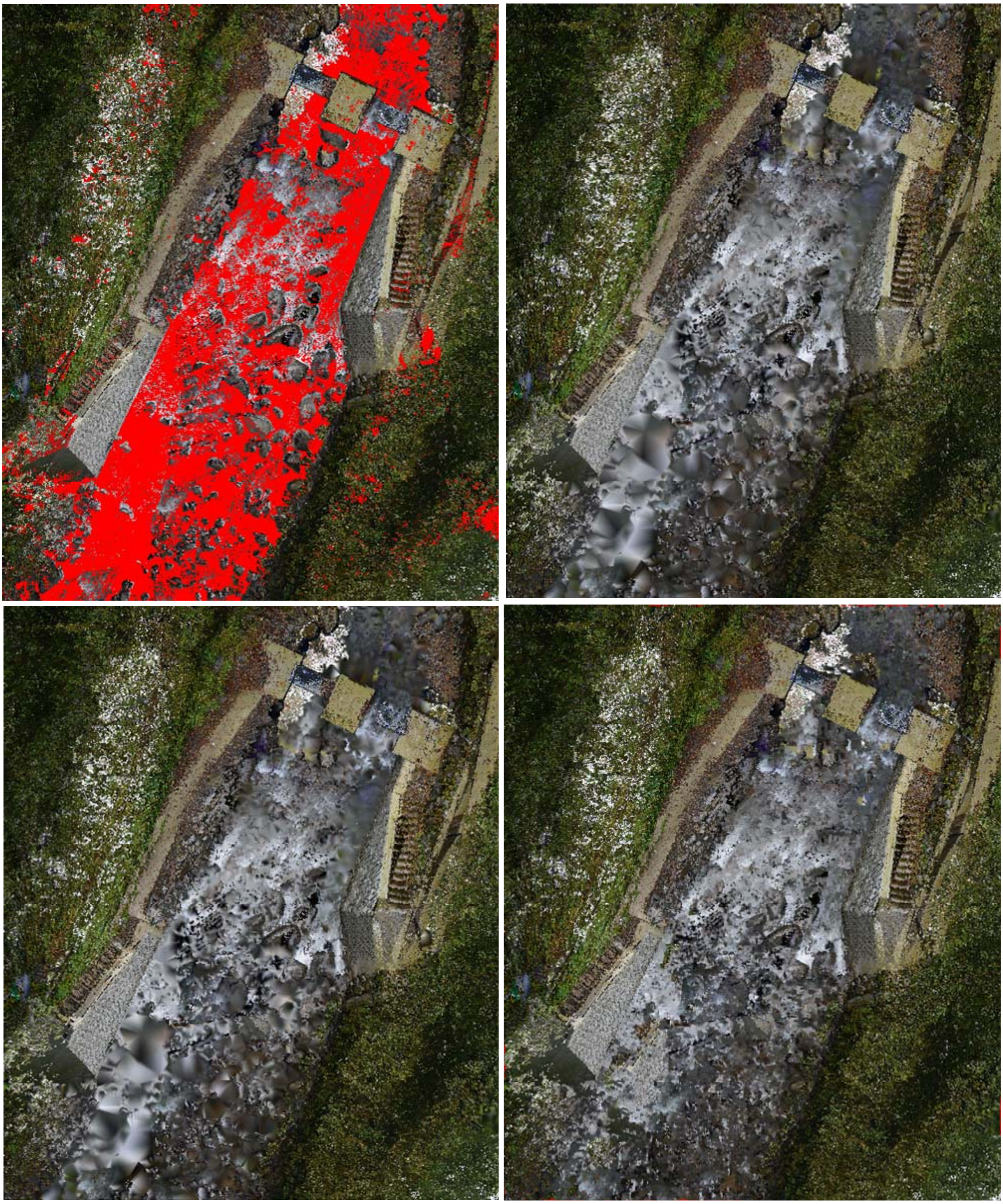

Fig. 5 Processing results using an outdoor environment dataset (upper-left: input data, upper-right: linear interpolation, bottom-left image: cubic interpolation, bottom-right image: inpaint-based interpolation

The processing time in each inpainting process is shown in Figure 6. Although the inpainting required approximately 10 times the processing time compared with other interpolations, we confirmed that the inpainting processing could deliver a more natural output result.

	Block 1	Block 2
Nearest neighbor	98.9 [sec]	106.5 [sec]
Linear	96.7 [sec]	94.7 [sec]
Cubic	101.9 [sec]	102.0 [sec]
Inpaint-based	811.1 [sec]	1313.0 [sec]

Fig. 6 Processing time

CONCLUSION

We have developed an inpainting approach for a colored DEM generation using a colored point cloud. Moreover, we have conducted an experiment using a terrestrial laser scanner. Through the experiment, we confirmed that our approach could reconstruct natural textures and colored DEMs from colored point cloud data with the missing areas. For our future works, there are some issues that require further investigation such as processing accuracy and processing speed.

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