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Title: Common-hole Filling for Boundary Noise Removal in VSRS
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1. Introduction

This document describes the common-hole filling method for common hole in VSRS. The common hole arises when a certain region is uncovered in any reference view but in the virtual view. It is not a serious problem in the most of 3DV sequences but 'Café' sequence; because most of 3DV sequences have few common holes. The VSRS employs the inpainting method to fill those common-holes but it generates annoying textures. In order to reduce such artifacts, we proposed a hole filling method which is modified bilateral filtering incorporates the available depth values around the common-hole. It is a mask-based hole filling method; hence it is fast and simple. We have implemented this method in boundary noise removal method, and it is used for EEs on 'Café' sequence.

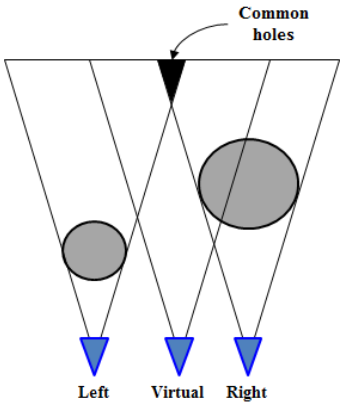


Fig. 1. Common hole

2. Common Holes and Visual Artifacts

2.1. Common Holes and Filling Methods

The common hole arises when a certain area is not covered at the reference views but the target virtual viewpoint as shown in Fig. 1. Some regions behind an object in a scene cannot be seen to the camera; those are called occluded regions. On the contrary, when

we change the viewing position, some regions are revealed newly; those are called disoccluded regions. To synthesize a high-quality image, we need to fill those disoccuded regions. If we have more than two reference images to generate an intermediate virtual viewpoint image, this disocclusion problem can be solved easily at most cases, since most disoccluded regions can be filled by referring to the other reference views.

The general mode in VSRS software uses the inpainting method to fill the common-hole [1]. It is designed for reconstructing damaged portions of images as shown in Fig. 2. Generally a mask is used to indicate which image regions need to be inpainted. Next, color information is propagated inward form the region boundaries, i.e., the known image information is used to fill in the missing areas

Fig. 2. Inpainting: "damaged" image, mask, and result after inpainting.

Similarly with the inpainting method, the boundary noise removal method also fills in the common-hole using the adjacent pixel values. In boundary nose removal, we used the pixel values having the lowest depth value among adjacent two valid depth values in horizontal as shown in Fig. 3. The left region of the common hole have lower depth value than that of the right region, we copy the left color values in horizontal direction.

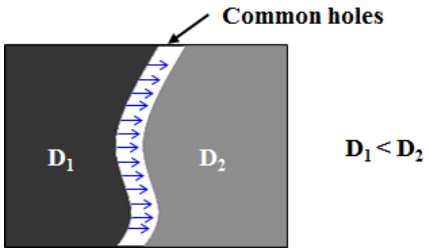
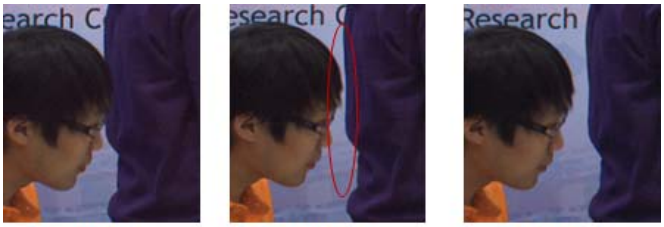


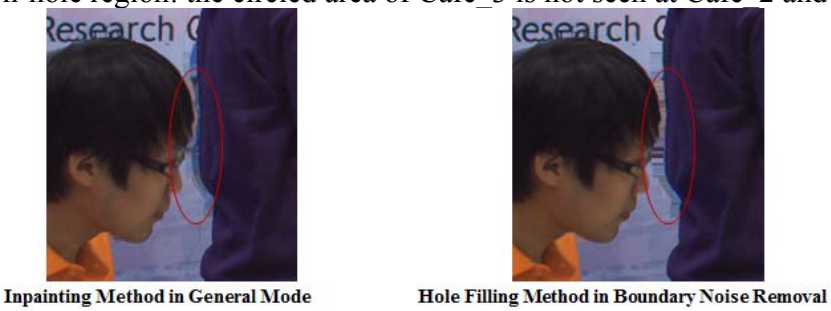
Fig. 4. Common-hole Filling in Boundary Noise Removal

2.2. Visual Artifacts on 'Café' Sequence due to Common-Holes

As we mentioned above, most of 3DV sequences have minor common-hole problem because there are few common-holes when we generate the virtual view images. However, Café sequence have serious common-hole problem. Café sequence is relatively complex sequence; structure of the scene is complex. Figure 5 shows the common-holes and the hole filled images using both the inpainting method and the hole filling method in boundary noise removal. Figure 5(a) explains the commonly invisible area at both reference views; the circled area of Café_3 is invisible at both Café_2 and Café_4. Figure 5(b) shows the results of hole filled images using both the inpainting method in general mode and the hole filling method in boundary noise removal. Both images have annoying visual artifacts; this should be minimized.



(a) Common-hole region: the circled area of Café_3 is not seen at Café_2 and Café_3



(b) Hole filled images using two methods

Fig. 5. Visual artifacts due to the common-hole filling methods

3. Proposed Hole Filling Method

In this section, we describe the proposed common-hole filling method. Figure 6 shows the procedure of the proposed method which consists of two steps: determining the depth value of the common hole and hole filling using the proposed bilateral filter. To fill in the common-holes, we considered two properties as:

- The common-hole might be the background or the furthest object around the hole.
- Hence, the depth value of the common-hole may have the same value of the background or the depth value of the furthest objet.

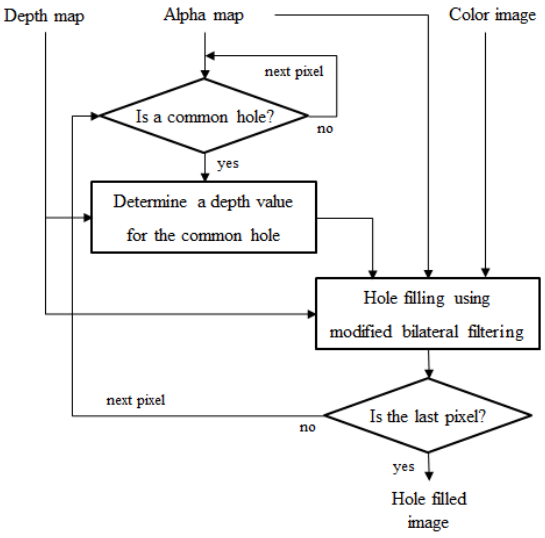


Fig. 6. Proposed hole filling method

3.1. Determining Depth Value for the Common Hole

Note that the common-hole is newly revealed region at the virtual viewpoint; there are no corresponding textures at the reference views due to the foreground objects. Therefore, the common-hole might be the background object or the smallest depth value around the hole. This can be rewritten as:

$$\begin{cases} \hat{d} = \min D(u,v) \\ D(u,v) \in W \end{cases} \tag{1}$$

Following Fig. 7 describes this procedure. If there are three objects, three representative depth values are available for the common hole. Among them we choose the smallest depth value. Using the determined depth value, we perform the hole filling process using three information: the alpha map, the depth map and the color image.

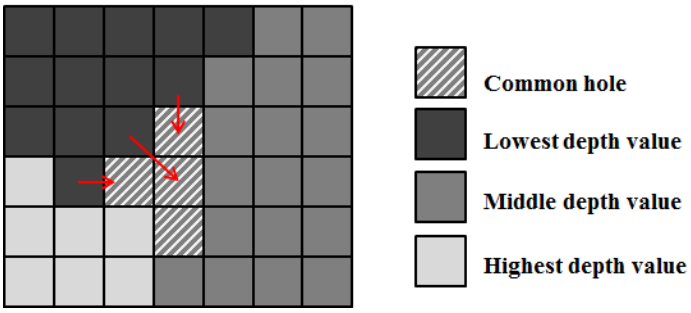


Fig. 7. Determining depth value for the common hole

3.2. Hole Filling Method using Modified Bilateral Filter

To determine a proper color for the common hole, we consider three data as we mentioned above. Differently from the typical inpainting method, we use the depth data. Since the depth value describes the distance between an object and the camera, we can notice which object is close one and the other. Using this property, we designed an efficient hole filling filter modified from the typical bilateral filter. Equation (2) is the proposed hole filling filter (or method). Let the synthesized image with common holes from view synthesis be I, the alpha map α, the depth map D, and bilateral filter radius be r. For a typical pixel p = {x, y}, assume $\vec{u}_p = \{x - r, \cdots, x + r\}$, $\vec{v}_p = \{y - r, \cdots, y + r\}$, we determine the color of the common hole C as:

$$C(x,y) = \frac{\sum_{u \in \vec{u}_p} \sum_{v \in \vec{v}_p} W(u,v,\hat{d}) \cdot C(u,v)}{\sum_{u \in \vec{u}_p} \sum_{v \in \vec{v}_p} W(u,v,\hat{d})} \tag{2}$$

where

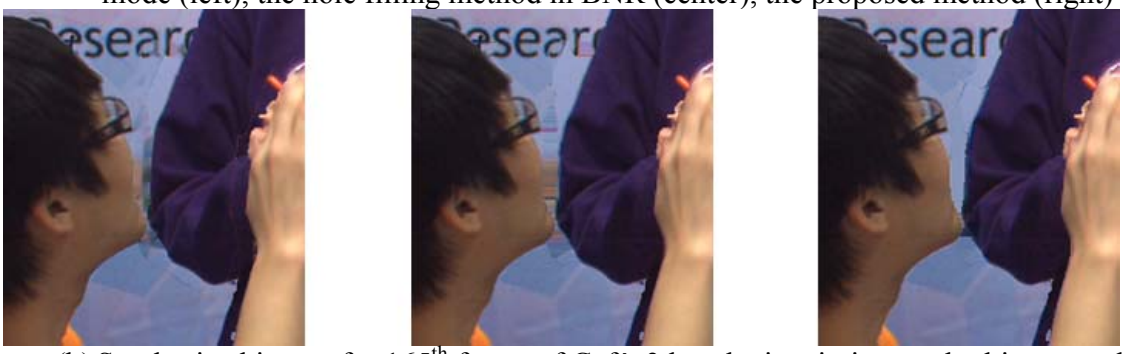
$$W(u,v,\hat{d}) = \exp\left(\frac{\left\| \hat{d}, D(u,v) \right\|^2}{2\sigma_D^2} \right) \exp\left(\frac{(x \quad u)^2 + (y \quad v)^2}{2\sigma_r^2} \right) \tag{3}$$

$$C(u,v) = \alpha(u,v) \cdot I(u,v) \tag{4}$$

4. Experimental Results

We have implemented this method in the boundary noise removal method; after removing boundary noises from each synthesized images, we fill the common holes using the proposed method. Since the Café sequence have serious problem by the common holes, we conducted the view synthesis experiments on it. We set the parameters as the bilateral filter radius r= 5, and the standard deviation σ_D = 10. We synthesized Café_3 images referring to two reference views, Café_2 and Café_4. Figure 8 shows the experimental results.

(a) Synthesized image for 81st frame of Café_3 by: the inpainting method in general mode (left), the hole filling method in BNR (center), the proposed method (right)



(b) Synthesized image for 165th frame of Café_3 by: the inpainting method in general mode (left), the hole filling method in BNR (center), the proposed method (right)

Fig. 8. Synthesized Image using three hole filing methods

We used this method for both EEs when we synthesize the intermediate view videos. The patch files of this method will be distributed as soon as possible when the SVN server is available.

5. Conclusion

In this contribution, we proposed the common-hole filling method for generating high-quality intermediate view image. Considering that the common-hole may be the background object or the furthest object around the hole, we estimate the depth value of a hole and determine the color value using the modified bilateral filter. Using this method, we confirmed that the visual artifacts were dramatically reduced.

6. Acknowledgements

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7. References

[1] A. Telea, "An image inpainting technique based on the fast marching method", J. Graphics Tools, vol.9, no.1, pp.25–36, 2004.