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Title: Implementation of Hole Filling Methods for VSRS 3.5.alpha
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1. Introduction

Dealing with holes in view synthesis is very important issue for 3D video systems. Previously, we have proposed two types of hole filling methods; common-hole filling and hole-filling for extrapolation [1],[2]. In the last meeting, proponents agreed with implementing the proposed methods into the current software [3]. Therefore, we have integrated two hole filling method onto VSRS 3.5.alpha.

2. Implemented Hole Filling Methods

2.1. Additional Parameter in VSRS

We implemented two hole filling method in VSRS 3.5.alpha, which is available in MPEG SVN server. We integrated both methods in *GeneralMode* in VSRS and added an additional parameter as *HoleFilling*. Below box describes the description on new parameters.

```
HoleFilling        2        # Valid for GeneralMode
                            # 0...Conventional inpainting,
                            # 1...Common-Hole(GIST),
                            # 2...Hole Filling for Extra.(GIST),
                            # 3...Spiral Exemplar Inpainting(ETRI)
                            # 4...Spiral Weight Average for Extra.(ETRI)
```

2.2. Common-hole Filling Method (mode 1)

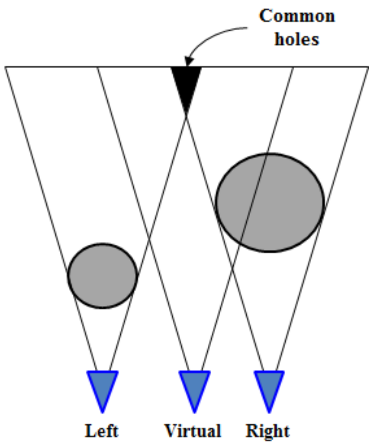


Fig. 1. Common hole

As we described in M18514, 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. To synthesize a high-quality image, we need to fill these disoccluded regions. We have proposed the common-hole filling method as depicted in Fig. 2, which consists of two steps: determining the depth value of the common hole and hole filling using the proposed bilateral filter.

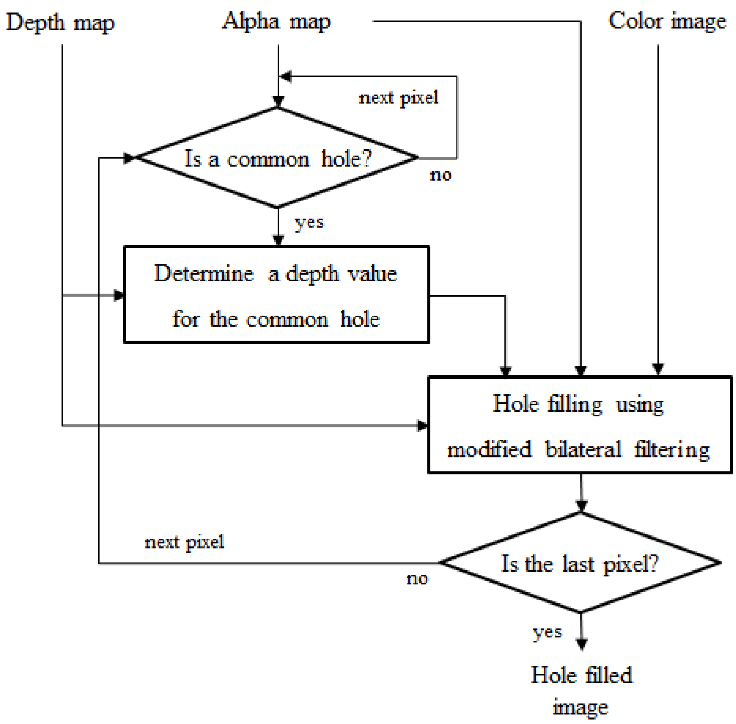


Fig. 2. Proposed common-hole filling method

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, most likely, the common-hole is the background object or the smallest depth value around the hole. This can be rewritten as:

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

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, · · ·, x + r}, $\vec{v}_p$ = {y − r, · · ·, 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

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

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

2.3. Hole Filling Method for Extrapolation (mode 2)

Since Guangzhou meeting, the view extrapolation has been investigated. As a response of EE2, we proposed a hole filling method for extrapolation in the last meeting. We regarded the hole regions as the extension of background. The proposed hole filling method consists of three steps:

- Step 1: Determine background pixels comparing valid depth values around hole area
- Step 2: Determine a depth value for the target hole pixel using adjacent valid depth values
- Step 3: Determine a color information of the hole pixel using the bilateral filter as described in Eq. (2).

With these three steps, only the boundary hole pixels to background are filled iteratively. As shown in Fig. 5, we determine which hole pixels needed to be filled first by comparing valid depth values around hole region. Simply, a pixel showing low depth is adjacent to the background region. Then, we determine a virtual depth value for the target hole pixel similarly with the common-hole filling method.

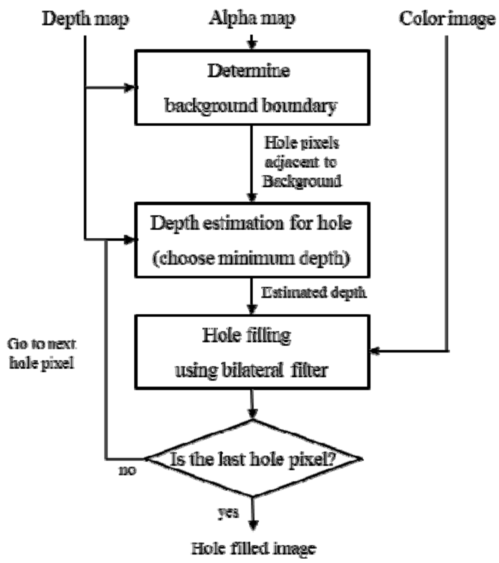


Fig. 3. Background hole filling method for extrapolation

Above proposed hole filling is designed for one still image; it does not consider temporal consistency. Temporally inconsistent virtual viewpoint video may have flickering artifacts; it is a several artifacts for 3D viewing. Therefore, we designed a temporal refinement method as shown in Fig. 4 that consists of two methods: availability of the hole area and fluctuation of depth value in both previous and current images. First, we check the usability of the previous frame for a hole area using both alpha maps, αt-1and αt. We copy the texture of hole area from the previous frame if there are valid textures which is visible (non-hole). In other words, if the region of hole area of the current frame is a hole area and that of the region of the previous frame is non-hole, we copy the texture of the previous frame if the depth difference is less than a threshold. Second, in the case that two frames have the same hole area between the previous and the current frame, we copy the texture of the previous frame if the depth value of current frame of the hole area is higher than that of the previous frame. This method reduces the temporal flickering

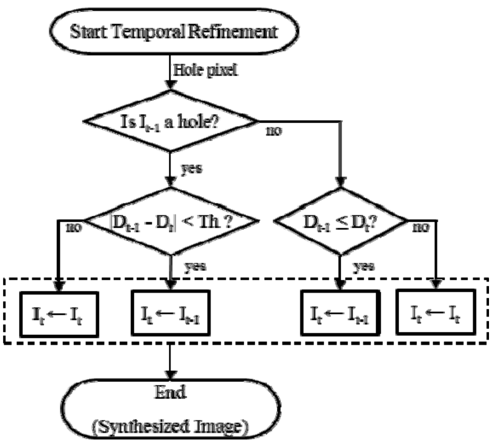
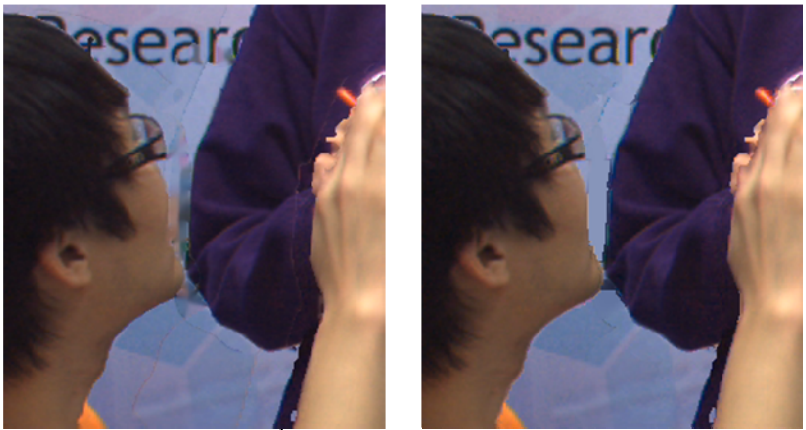


Fig. 4. Temporal refinement referring to the previous synthesized frame

3. Experimental Results

3.1. Experimental Results on the Common-Hole Filling Method

The common-hole problem is severe in Café sequence. We synthesized Café_3 images referring to two reference views, Café_2 and Café_4. Figure 5 shows the experimental results.



(a) Synthesized image for 165th frame of Café_3 by: mode 0 - the inpainting method in general mode (left), mode 1 - the proposed common-hole filling method (right)

Fig. 5. Synthesized images using three hole filing methods

3.2. Experimental Results on Extrapolation using Background Hole Filling Method

For evaluation of the proposed hole filling method, we tested test sequences of. All viewpoints were tested in full length of frames for 3D viewing. Figure 6 shows the visual comparisons; left images are the original views for the target views (mode 0) and right images show the proposed hole filling method (mode 2). As we shown in Fig. 6, hole regions of all objects in a scene were filled clearly with background color information.

(a) Results of 'Book_arrival' sequence

(b) Results of 'Newspaper' sequence

(c) Results of ‘Mobile’ sequence

(d) Results of ‘Cafe’ sequence

Fig. 6. Comparison of synthesized images using hole filling method for extrapolation: original view (left), mode 0 - the inpainting method in general mode (center), mode 2 - the proposed hole filling for extrapolation (right)

4. Conclusion

In this contribution, we described the implemented hole filling methods in VSRS 3.5. alpha. Using the common-hole filling method (mode 1), we fill in the uncovered area by the reference images effectively. Using the hole filing for extrapolation (mode 2), we fill the hole region using the background textures, iteratively and diffusively. The updated VSRS 35.alpha will be tested during Geneva meeting and have a new tag if it is permitted as reference software.

5. Acknowledgements

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6. References

[1] ISO/IEC JTC1/SC29/WG11, “Common-hole Filling for Boundary Noise Removal in VSRS,” m18514, Oct. 2010.

[2] ISO/IEC JTC1/SC29/WG11, “Results of View Synthesis using Modified Hole Filling Methods,” m19281, Jan. 2011.

[3] ISO/IEC JTC1/SC29/WG11 “Description of Exploration Experiments in 3D Video Coding,” N11630, Oct. 2010.