INTERNATIONAL ORGANISATION FOR STANDARDISATION
ORGANISATION INTERNATIONALE DE NORMALISATION
ISO/IEC JTC1/SC29/WG11
CODING OF MOVING PICTURES AND AUDIO

ISO/IEC JTC1/SC29/WG11
MPEG2011/M19281
January 2011, Daegu, Korea

Source: GIST (Gwangju Institute of Science and Technology)
Status: Proposal
Title: Results of View Synthesis using Modified Hole Filling Methods
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1. Introduction

Dealing with holes in view synthesis is very important issue for 3D video systems. This document describes two types of hole filling method for view synthesis. The first is the common-hole which has no reference information at the real views [1]. The second is the general hole which is newly revealed area at the virtual viewpoint. If the virtual view is at the interval of reference views, most of this hole can be filled by referring to the other reference view. If not, however, we should find alternative textures from the neighboring pixels. Especially, the extrapolation case for view synthesis needs this method [2]. In this document, we described not only the additional experiments of the common-hole filling, but also the hole filling method for extrapolation of view synthesis.

2. Common Holes and Filling Methods

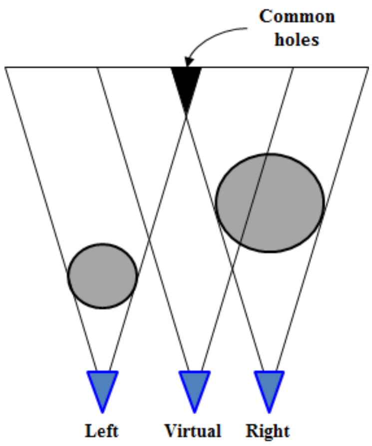


Fig. 1. Common hole

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 a 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 viewpoint images to generate an intermediate virtual viewpoint, this disocclusion problem can be solved easily at most cases, since most disoccluded regions exist at the other reference views

2.1. Proposed Hole Filling Method

We proposed the common-hole filling method in Guangzhou meeting. In this section, we describe the proposed common-hole filling method again. Figure 2 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.

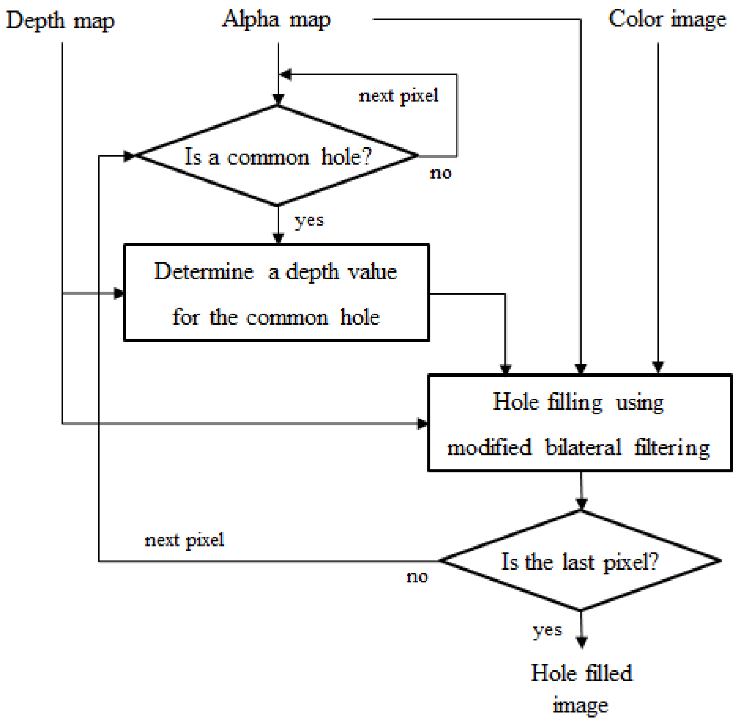


Fig. 2. Proposed hole filling method

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

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

Following Fig. 3 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 data: the alpha map, the depth map and the color image.

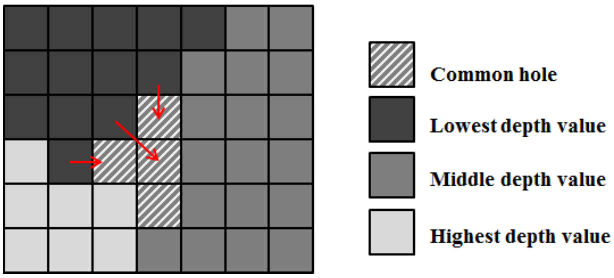


Fig. 3. Determining depth value for the common hole

2.3. 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, · · ·, x + r}, $\vec{v}_p$ = {y − r, · · ·, y + r}, we determine the color of the common hole *C* as:

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

where

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

$$C(u,v) = \alpha(u,v) \cdot I(u,v) \qquad (4)$$

3. Background Hole Filling Method for Extrapolation

Since the last meeting in Guangzhou, in initial study on the extrapolation capabilities of the view synthesis software VSRS was started. Although VSRS performs well for extrapolation, there are visible artifacts on the hole area. It is because that the hole filling method do not take the depth values of neighboring pixels into account; it is similar artifacts with the common-hole filling problem in VSRS. Therefore, we have developed a background hole filling method for extrapolation. Following the assumptions of the common-hole filling method, we regarded the hole regions as the extension of background; hence we named this hole filling method as background hole filling. 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 as shown in Fig. 4. Therefore, this method performs iterative way until entire hole regions are filled perfectly. In other words, it is performs in diffusive way. 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. Finally, we determine the color value for the target hole pixel using the bilateral filter using Eq. (2). Figure 6 shows an example of the background hole filling method. Using three types of data, the synthesized image with hole, synthesized depth with hole, and the mask image for hole, we filled the hole region from the background to the foreground by comparing the valid depth values.

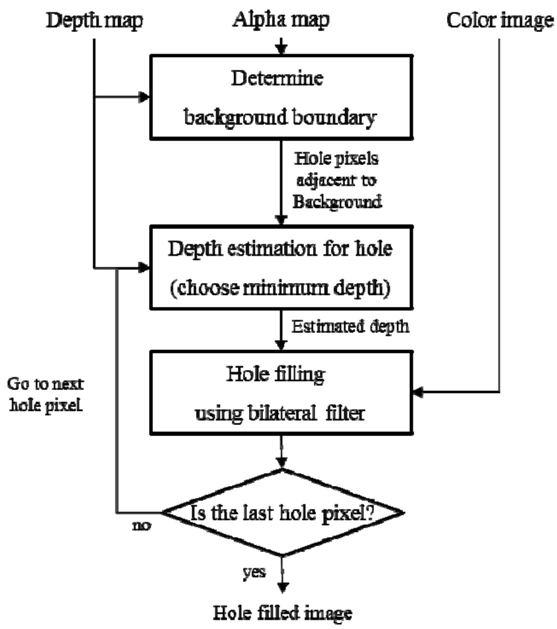


Fig. 4. Background hole filling method for extrapolation

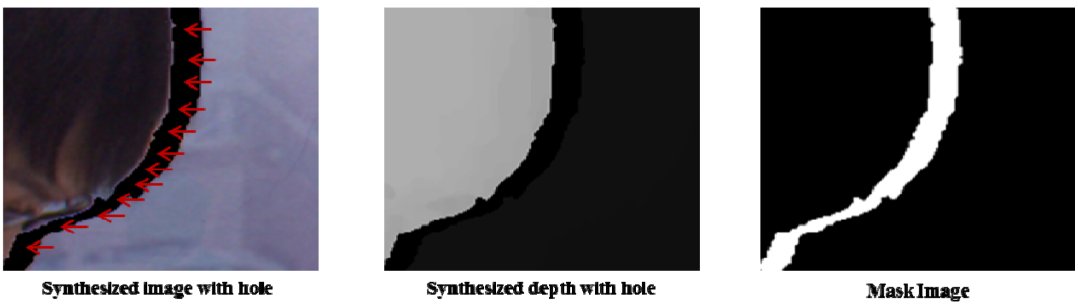
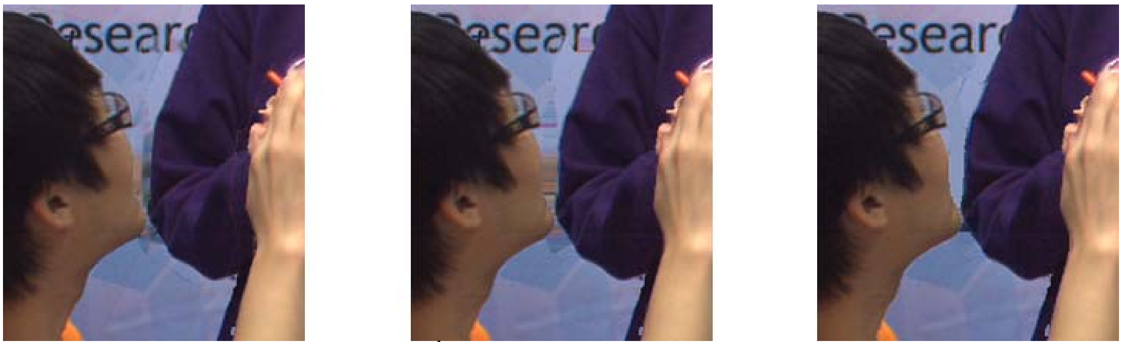


Fig. 6. Hole filling direction using synthesized depth image

4. Experimental Results

4.1. Experimental Results on the Common-Hole Filling Method

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 7 shows the experimental results.



(a) 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)

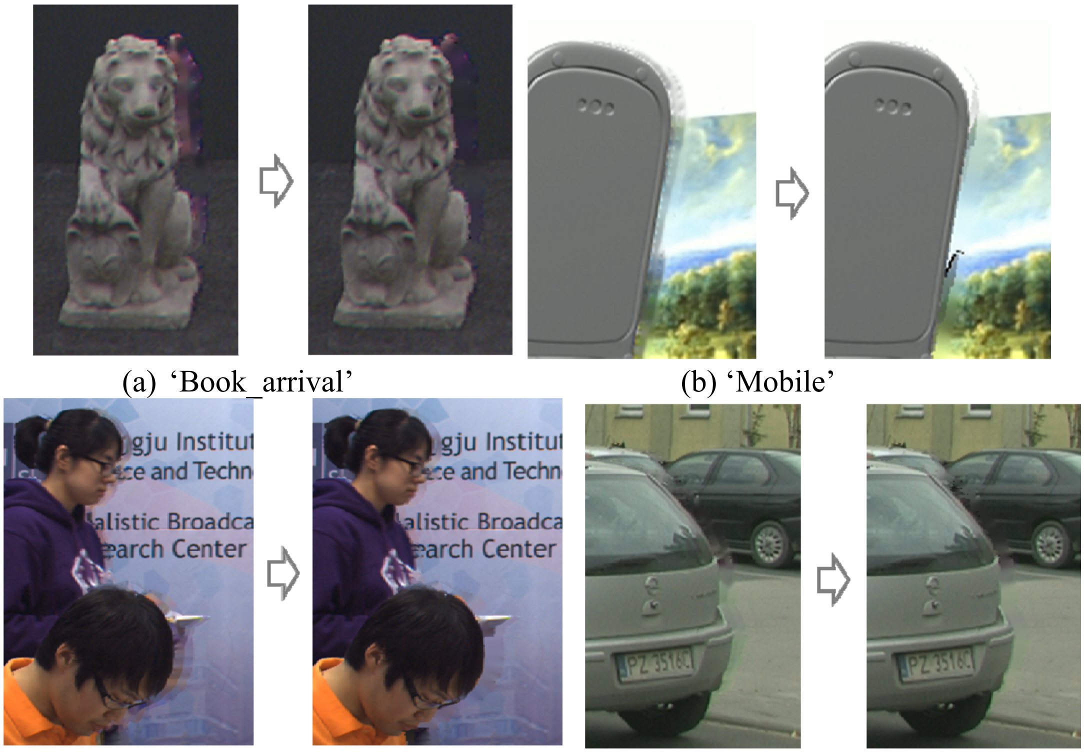
Fig. 7. Synthesized images using three hole filing methods

4.2. Experimental Results on Extrapolation using Background Hole Filling Method

For evaluation of the proposed hole filling method, we tested all test sequences of EE2 as described in Table 1 [3]. All viewpoints were tested in full length of frames for 3D viewing. Figure 8 shows the visual comparison; left and right images show the hole filled image using VSRS and the proposed hole filling method, respectively. Among seven test sequences we pasted four sequences. Other three sequences showed similar synthesis results in visual. As we shown in Fig. 8, hole regions of all objects in a scene were filled clearly with background color information.

Table 1: Input and output views for extrapolation experiments in 2-view configuration

Data set	**Original Pair (OL-OR)**	**Extrapolated Views**
Champagne_tower	39-41	41.5, 42, 42.5, 43
Book_arrival	10-8	7.5, 7, 6.5, 6
Newspaper	4-6	6.5, 7, 7.5, 8
Balloons	3-5	5.5, 6, 6.5, 7
Mobile	5-7	7.5, 8, 8.5, 9
Café	2-4	4.5, 5, 5.5, 6
Poznan_Street	4-3	2.75, 2.5, 2.25, 2



(a) 'Book_arrival' (b) 'Mobile'

(c) 'Café' (d) 'Poznan_street'

Fig. 8. Comparison of synthesized images using background hole filling method

5. Conclusion

In this contribution, we proposed the two types of filling methods for generating a high-quality virtual viewpoint image. Using the common-hole filling method, we can fill in the uncovered area by the reference images effectively. By modifying this method for extrapolation, we proposed the background hole filling method. It fills the hole region using the background texture information iteratively and diffusively. For evaluating the results in public, we will bring all synthesized results to Daegu meeting.

6. Acknowledgements

This research is supported by Ministry of Culture, Sports and Tourism (MCST) and Korea Creative Content Agency (KOCCA) in the Culture Technology (CT) Research & Development Program 2010.

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.

[2] ISO/IEC JTC1/SC29/WG11 "Common-hole Filling for Boundary Noise Removal in VSRS," m18514, Oct. 2010.
[3] ISO/IEC JTC1/SC29/WG11 "Description of Exploration Experiments in 3D Video Coding," N11630, Oct. 2010.