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Title: 3D-CE3 related: Depth upsampling using depth edge detection
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1. Introduction

This document describes the depth upsampling algorithm performing as a post-processing in 3DV-ATM ver. 0.3. Since the resolution of input depth maps is lower than the resolution of input texture images, an effective depth upsampling method is required to have the same resolution with the texture video. In this document, we propose a new depth upsampling method using depth edge detection to enhance the quality of synthesized image. Our method is compared with the conventional upsampling method, e.g., the bilinear interpolation and Lanczos3 upsampling. Experiments were conducted as described in the Call for Proposals (CfP) [1] and the common test condition in 3D Video Coding (3DVC) [2].

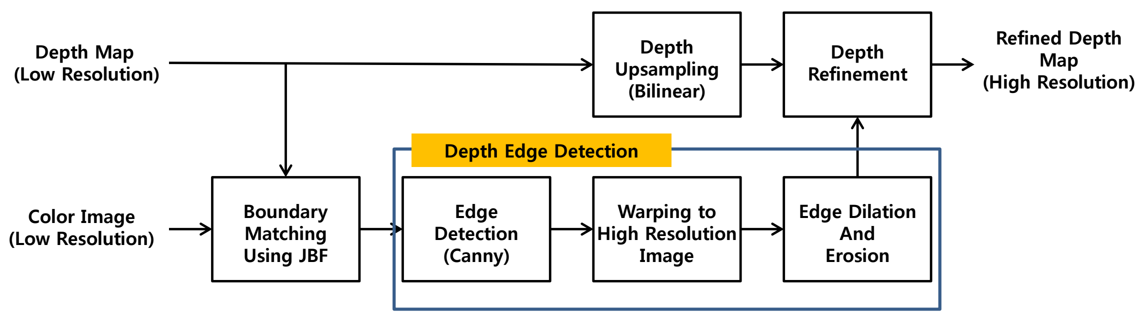
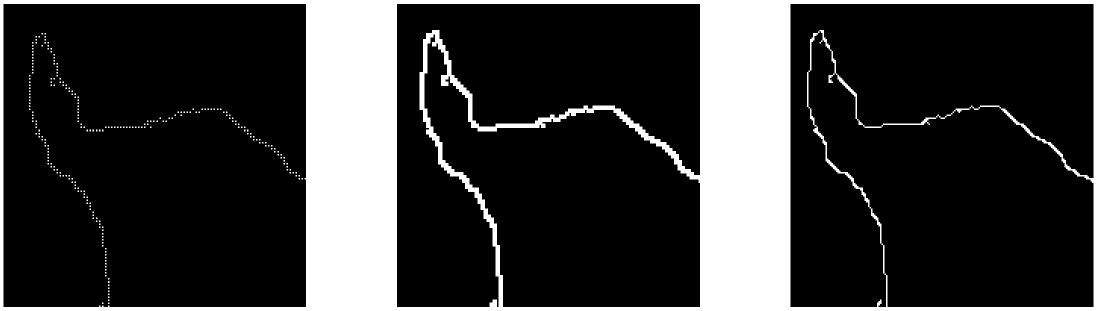


Fig. 1. Block diagram of the proposed method

2. Depth Edge Detection

In the 3DVC experimental environment, the resolution of input depth maps is lower than the resolution of input texture images. First, we extract an edge map from the low-resolution depth map, and the edge map is converted to high-resolution one. For this, Canny edge detection is first used to obtain an edge map E_L from a low-resolution depth map. Then, we apply an edge-map warping operation to E_L for generating the high-resolution edge map E_H; the warped edge maps into high resolution image are shown in

Fig. 2(a). In order to obtain the one-pixel-width edge contour map from the high-resolution edge map, we apply some morphological operations such as dilation and erosion, sequentially. These three-step processes are shown in Fig. 2.



(a) warped edge (b) edge dilation (c) edge erosion

Fig. 2. Process to obtain depth edges

3. Boundary Matching

The quality of depth maps are usually degraded by coding errors during low bit-rate depth map compression. Consequently, since the edge information of a decoded depth map becomes weak, object boundaries in it are not matched well with ones in the texture image. The problem makes the quality of synthesized image degraded. Hence, it is needed to develop a method to restore edges in the depth map. In boundary matching, we employ a joint bilateral filter (JBF) [3] to solve the unmatched boundary problem.

QP size 26 QP size 36 QP size 46

Fig. 3. Blocking artifacts by QP size

Eq. (1) and Eq. (2) are two weighting functions of JBF. The center pixel is refined by Eq. (3) using its neighboring pixels. As shown in Fig. 4, we can obtain an enhanced depth map and its edge map via JBF.

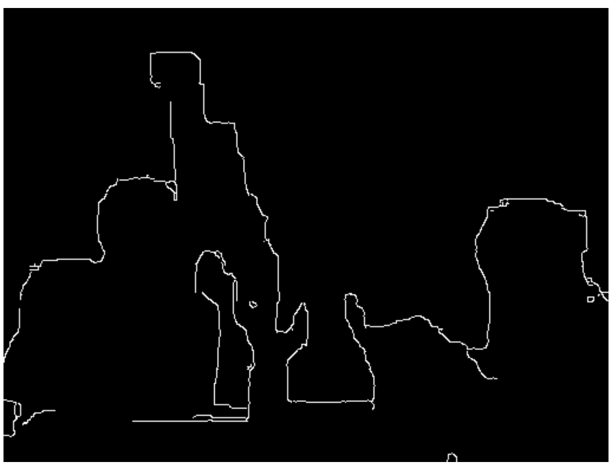
$$W(u,v) = \exp\left(-\frac{\left\| I(x,y), I(u,v) \right\|^2}{2\sigma_R^2}\right) \cdot \exp\left(-\frac{(x-u)^2 + (y-v)^2}{2r^2}\right) \tag{1}$$

$$C(u,v,d) = \min(\lambda, \left| D(u,v) - d \right|) \tag{2}$$

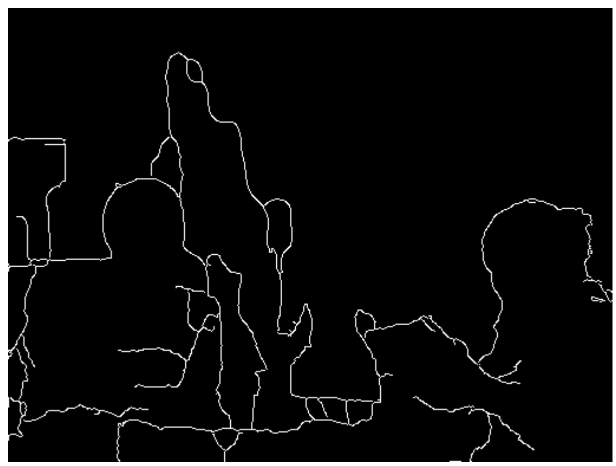
$$D(x,y) = \arg\min_{d \in \vec{d}_p} \frac{\sum_u \sum_v W(u,v) \cdot C(u,v)}{\sum_u \sum_v W(u,v)} \tag{3}$$

(a) depth map before JBF

(b) depth map after JBF



(c) depth edges before JBF



(d) depth edges after JBF

Fig. 4. Depth edge refinement

4. Depth Upsamping

In depth upsampling, a low-resolution depth map is upsampled to a high-resolution one with the aid of high-resolution edge information in Fig. 4(d). For this, a low-resolution depth map is first enlarged by a bilinear interpolation method. During bilinear interpolation, the depth information near edges becomes linear. During depth upsampling, we refer the high-resolution depth edge map (Fig. 4(d)) so as to make those linear depth data discrete.

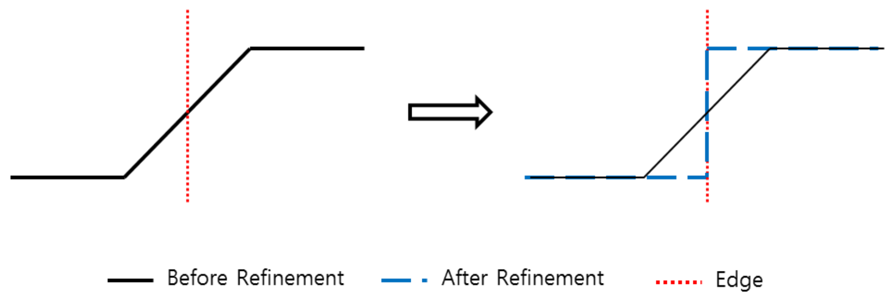


Fig. 5. Depth data discretization

As shown in Fig. 5, the linear depth data near edges is first replaced by the closest original depth data, not newly-generated depth data by bilinear interpolation. To determine depth information at an edge pixel, 4-connected neighbors of the edge pixel are found. If the left pixel of the edge pixel is not an edge pixel, its depth value is set to the left depth value. The priority of depth value assignment using 4-connected neighbors is left, upper, right, and lower depth values. Fig. 6 shows that process of filling edge pixels.

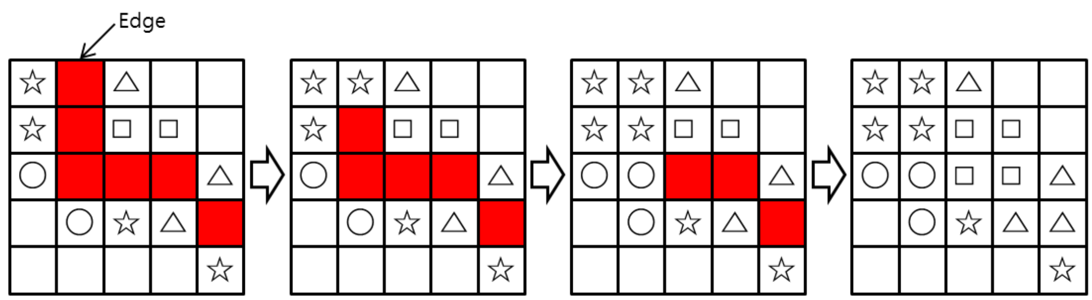


Fig. 6. Depth value selection of edge pixels

5. Experimental Results

The proposed method using depth edge detection is implemented under the common test condition in 3D Video Coding (3DVC) as a post processing.

Table 1. Coding results

Sequence	BD-Rate of synthesized (%)	BD-PSNR of synthesized (dB)
S01	-	-
S02	0.24	0.00
S03	-7.39	0.22
S04	0.13	0.00
S05	1.75	-0.07
S06	2.53	-0.11
S08	1.54	-0.04
Average	-0.2	0.00

Table 2. Encoder complexity

Sequence	Encoder time (%)
S01	-
S02	104.61
S03	103.43
S04	104.55
S05	102.29
S06	101.66
S08	102.53
Average	103.17

6. Conclusion

In this document, we have proposed a new depth upsampling method using depth edge detection. The experimental results showed -0.2% dBR and 0 dB dPSNR.

7. Acknowledgement

This work was supported by Samsung Electronics Co. Ltd.

8. References

[1] ISO/IEC JTC1/SC29/WG11, "Call for Proposals on 3D Video Coding Technology," *in MPEG output document* N12036, March 2011.

[2] ISO/IEC JTC1/SC29/WG11, "Common Test Conditions for AVC and HEVC-based 3DV," *in MPEG output document* N12560, Feb. 2012.

[3] Qingxiong Yang, Liang Wang, and Narendra Ahuja, "A Constant-Space Belief Propagation Algorithm for Stereo Matching," in *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)* 2010.