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Title: 3D-CE4.a related: Depth boundary filtering
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1. Introduction

This document includes a description the proposed depth boundary filtering method. We plan to apply the proposed method at loop filtering for depth by the next meeting.

2. Depth Boundary Filtering

In this document, the method is applied to coded/upsampled depth views. The flowchart is shown in Fig. 1. Initially, boundary pixels are extracted and then filtered based on three factors: depth similarity, distance, and direction.

2.1 Boundary pixel extraction

The proposed filter targets near-boundary pixels. Boundary information can be estimated by calculating gradient magnitude of each pixel. The gradient magnitude's standard deviation represents the amount of edge information. Thus, we use this as a threshold for selecting near-boundary pixels. Once threshold is estimated in the first frame, we use the value throughout the sequence. In addition, a 3x3 mask is used to expand targets for filtering.

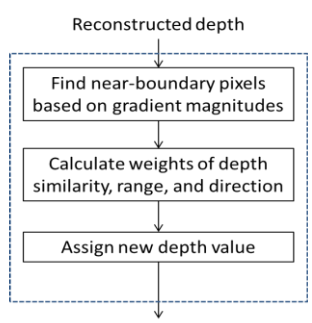


Fig. 1. Flowchart of the proposed filtering

2.2 Trilateral filtering: depth similarity, distance, and direction

Filtering is based on three factors: depth similarity, distance, and direction. Fig.1. shows the weight position regarding the boundary pixel direction. Eq. (1) and Eq. (2) represent the weight formula for depth similarity and distance, respectively.

We assign more weights to pixels which possess depth values similar to the current pixel. In detail, we discard the pixels which are unlikely to be near the current pixel. Hence, we represent this similarity term as:

$$w\_sim_{p,q} = \exp\left(\frac{-\left| D_p - D_q \right|^2}{2\sigma^2} \right) \tag{1}$$

Unlike the range term of the bilateral filter, we apply more range weight to farther pixels. We assume that pixels farther from the boundary present less error.

$$w\_range_{p,q} = \exp\left(\frac{(p_x - q_x)^2 + (p_y - q_y)^2}{2\sigma^2} \right) \tag{2}$$

Regarding the direction weight, initially we define four directions: horizontal, vertical, diagonal upleft, and diagonal upright. Fig. 2 represents partitions between the defined directions. The direction weight is centered at the orthogonal direction of the boundary pixel direction. Fig. 3 shows that the direction weights in accordance to boundary directions are by strongly distributed near the orthogonal direction.

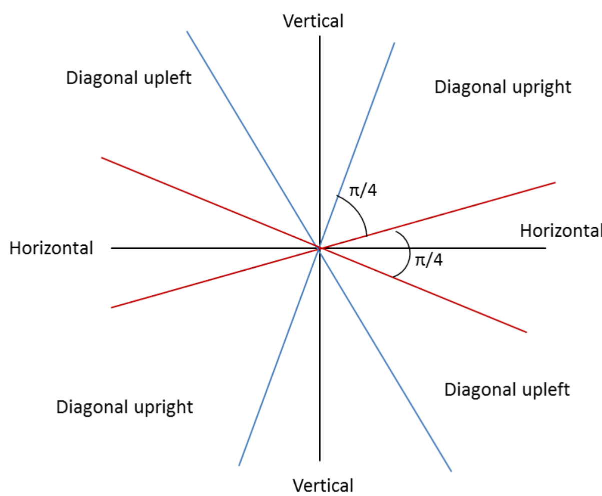
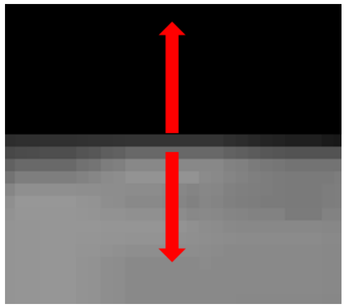
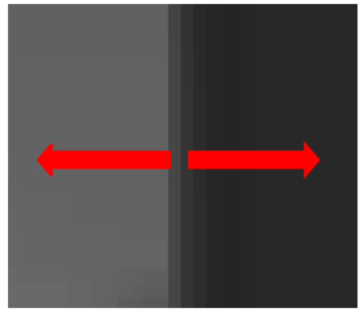


Fig. 2. Direction partitions

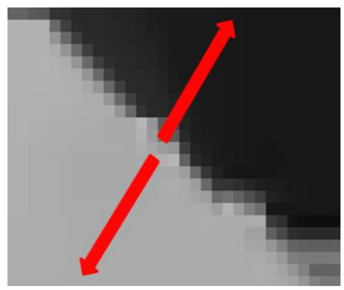


(a) Horizontal



(b) Vertical

(c) Diagonal upright



(d) Diagonal upleft

Fig. 3. Weights toward the orthogonal of boundary direction

We designed a function to assign the highest weight to the orthogonal direction. First we find the angle between the boundary direction and the orthogonal direction. Eq. (3) shows the formula. The range for angle $\theta_{p,q}$ is adjusted to keep the weight in between 0 and 1. Using Eq. (3) and a 9x9-sized window, we pre-calculate the weights as in Table 1. Weights are symmetric in respect to the boundary direction.

$$w\_direction = 1 - \cos(\theta_{p,q}), \quad 0 \le \theta_{p,q} \le \frac{\pi}{2} \tag{3}$$

Table 1. Weights for each direction

0.29	0.4	0.55	0.76	1	0.76	0.55	0.4	0.29
0.2	0.29	0.45	0.68	1	0.68	0.45	0.29	0.2
0.11	0.17	0.29	0.55	1	0.55	0.29	0.17	0.11
0.03	0.05	0.11	0.29	1	0.29	0.11	0.05	0.03
0	0	0	0	0	0	0	0	0
0.03	0.05	0.11	0.29	1	0.29	0.11	0.05	0.03
0.11	0.17	0.29	0.55	1	0.55	0.29	0.17	0.11
0.2	0.29	0.45	0.68	1	0.68	0.45	0.29	0.2
0.29	0.4	0.55	0.76	1	0.76	0.55	0.4	0.29

(a) Horizontal boundary (weight: vertical)

0.29	0.2	0.11	0.03	0	0.03	0.11	0.2	0.29
0.4	0.29	0.17	0.05	0	0.05	0.17	0.29	0.4
0.55	0.45	0.29	0.11	0	0.11	0.29	0.45	0.55
0.76	0.68	0.55	0.29	0	0.29	0.55	0.68	0.76
1	1	1	1	1	1	1	1	1
0.76	0.68	0.55	0.29	0	0.29	0.55	0.68	0.76
0.55	0.45	0.29	0.11	0	0.11	0.29	0.45	0.55
0.4	0.29	0.17	0.05	0	0.05	0.17	0.29	0.4
0.29	0.2	0.11	0.03	0	0.03	0.11	0.2	0.29

(b) Vertical boundary (weight: horizontal)

0	0.01	0.05	0.14	0.29	0.49	0.68	0.86	1
0.01	0	0.02	0.11	0.29	0.55	0.8	1	0.86
0.05	0.02	0	0.05	0.29	0.68	1	0.8	0.68
0.14	0.11	0.05	0	0.29	1	0.68	0.55	0.49
0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
0.49	0.55	0.68	1	0.29	0	0.05	0.11	0.14
0.68	0.8	1	0.68	0.29	0.05	0	0.02	0.05
0.86	1	0.8	0.55	0.29	0.11	0.02	0	0.01
1	0.86	0.68	0.49	0.29	0.14	0.05	0.01	0

(c) Diagonal Upleft boundary (weight: diagonal upright)

1	0.86	0.68	0.49	0.29	0.14	0.05	0.01	0
0.86	1	0.8	0.55	0.29	0.11	0.02	0	0.01
0.68	0.8	1	0.68	0.29	0.05	0	0.02	0.05
0.49	0.55	0.68	1	0.29	0	0.05	0.11	0.14
0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
0.14	0.11	0.05	0	0.29	1	0.68	0.55	0.49
0.05	0.02	0	0.05	0.29	0.68	1	0.8	0.68
0.01	0	0.02	0.11	0.29	0.55	0.8	1	0.86
0	0.01	0.05	0.14	0.29	0.49	0.68	0.86	1

(d) Diagonal Upright boundary (weight: diagonal upleft)

3. Experimental Results

The proposed method was implemented on 3DV-ATM (v0.3) under the common test conditions [1]. The filter was applied to the reconstructed depth view (upsampled) as a post-processing. The same sigma value was used for both similarity and range weights, we selected 10. The BD-rate and BD-PSNR were -2.93% and 0.10 dB for EHP. Encoder complexity was nearly 100%. Decoder complexity will be evaluated in the future work.

Table 2. Coding results

Sequence	BD-Rate of synthesized (%)	BD-PSNR of synthesized (dB)
S01	-	-
S02	-0.85	0.03
S03	-8.43	0.25
S04	-2.58	0.08
S05	-2.02	0.09
S06	0.00	0.00
S08	-3.69	0.14
Average	-2.93	0.10

Table 3. Encoder time complexity

Sequence	Encoder time (%)
S01	-
S02	100.60
S03	100.00
S04	100.37
S05	100.90
S06	100.73
S08	100.69
Average	100.55

4. Conclusion

We introduced a filter which targets near-boundary pixels. Three factors are considered: depth similarity, range, and direction. The filter was applied to reconstructed depth views at the encoder. Resulting dBR and dPSNR were -2.93% and 0.10 dB. We plan to apply the proposed method at loop filtering for depth by the next meeting.

5. Acknowledgment

This work was supported by Samsung Electronics Co. Ltd.

6. References

[1] ISO/IEC JTC1/SC29/WG11 "Common Test Conditions for AVC and HEVC-based 3DV," N12560, Feb. 2012.