Fast Joint Bilateral Upsampling using Color Edge Information

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***Abstract*—In this paper, we propose a new depth image upsampler to increase the depth image resolution fast while protecting edge information. We use a Canny edge detector for reduced computational complexity. Joint bilateral upsampler (JBU) increases the resolution of a depth image considering the photometric property of corresponding high-resolution color image. The JBU uses both a spatial weighting function and a color weighting functions evaluated on the data values. In the proposed upsampler, a color weighting function is chosen by edge existence. Experimental results show that the proposed upsampler out performs JBU, in terms of a trade-off between depth image quality and computational complexity.**

Keywords—joint bilateral filter; depth map upsampling

I. INTRODUCTION

Accurate and high resolution depth sensing is a fundamental challenge in the three-dimensional (3D) video applications. Recently, Time-of-Flight (ToF) range camera and KINECT depth camera became a popular alternative for dense depth sensing. Depth images captured by active range cameras usually have low resolution [1], [2]. For the actual utilization, we should be the same resolution of the depth image and color image [3]. Therefore, an efficient depth upsampling is necessary. Former image upsamplers, such as bilateral upsampler (BU), can be directly used own image for depth upsampling [4]. But filter-based methods should caused over smooth at the depth discontinuity regions. Yang *et al*. applied bilateral filtering to a depth cost volume and a color image in an iterative refinement process [5]. In order to increase the resolution and reduce depth image errors, Chan *et al*. used a noise aware joint bilateral filter [6].

A joint bilateral upsampler (JBU) removes the over smooth at the depth discontinuity region by adding additional information[7]. The information is an original color image used in depth estimation. But there are two problems on JBU: computational complexity and visual artifacts. Since JBU uses color data additionally, it cause much slower than other upsamplers.

In this paper, we propose a new depth image upsampler that uses edge information to decide the weighting functions in JBF. To reduce the computational complexity, we perfom edge detection before the JBU. Based on edge map, we can decide to use spatial weighting function or color weighting function, or both. In our experiments, the proposed upsampler makes high-resolution depth images fast while protecting edge information.

II. FAST JOINT BILATERAL UPSAMPLING USING COLOR EDGE INFORMATION

In JBU algorithm, the upsampled depth image is obtained via the Gaussian weighted sum of neighbors within a filter kernel. Assume that there are a low resolution depth image D^l, a high resolution depth image D^h and high resolution color image I^h. Let p and q denote coordinates of pixels in I^h, and $p_\downarrow$ and $q_\downarrow$ denote the associated coordinates in D^l. The center pixel at a local window $W\times W$ is p. The neighboring pixel of p at the window is q where $q \in W\times W$. Formally, the depth value D_p^h at p in an upsampled depth image D^h is computed by JBU as Eq. (1).

$$D_p^h = \frac{\sum_{q\in w\times w} \gamma_{p,q}\, D_q^l}{\sum_{q\in w\times w} \gamma_{p,q}}, \tag{1}$$

where $\gamma_{p,q}$ is a kernel weighting function.

$\gamma_{p,q}$ is defined by Eq. (2).

$$\gamma_{p,q} = \alpha(\| p_\downarrow - q_\downarrow \|) \cdot \beta(\| I_p^h - I_q^h \|), \tag{2}$$

where α and β are spatial and the color weighting functions, respectively, and $\|\cdot\|$ is an Euclidean distance operator. If we modeling α and β using an exponential function, those weighting functions are represented by Eq. (3).

$$\alpha(x) = \exp\left(\frac{-x^2}{\sigma_\alpha}\right),\ \beta(x) = \exp\left(\frac{-x^2}{\sigma_\beta}\right). \tag{3}$$

The smoothing parameters of α and β are can be represented by σ_α and σ_β.

The final goal of JBU is upsample of low resolution depth image while protecting the edge information. If we know the edges before the JBU, then we can reduce the computational complexity. In our algorithm we use the Canny edge detector to get the edge information when before the JBU [8]. Figure 1 shows the result of the Canny edge detection.

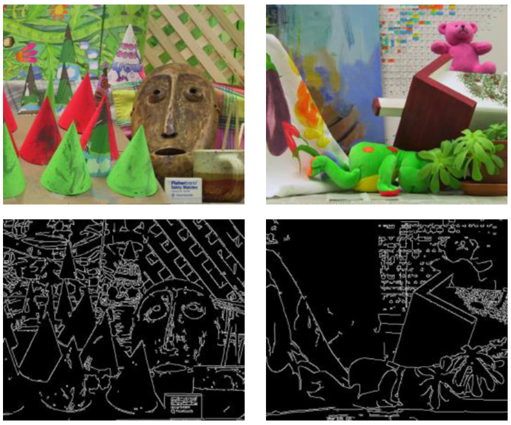


Fig. 1. Result of the Canny edge detection

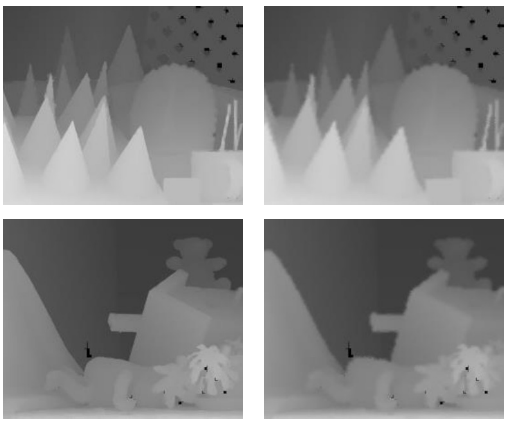
According to the color edges, we choose different weighting functions for depth image upsampling. For the edge pixels, we use spatial and color weighting functions like JBU. Otherwise, we use only spatial weighting functions as Eq. (4).

$$\gamma_{p,q} = \alpha(\| p_{\downarrow} - q_{\downarrow} \|). \quad (4)$$

The only difference to between Eq. (2) and Eq. (4) is that the color weighting functions are not used.

III. Experimental Results

In our experiment, we have used two test image sets, 'Cones' and 'Teddy', provided by the Middlebury Stereo were used [9]. The ground-truth depth images were downsampled by factors of 4 and 8, using the nearest neighbor method. In the experiment, the size of local window was set to 5×5. The smoothing parameters of α and β are were set to 3 and 30.



JBU Proposed

Fig. 2. Upsampled depth images

The proposed methods is compared with the JBU. Fig 2 shows the upsampled depth maps of 'Cones' and 'Teddy' of the scaling factor 4. Table 1 shows bad pixel rate (BPR), that was calculated with respect to the ground-truth depth images. We can find that joint bilateral upsampler have much lower BPR than our method.

TABLE I. Performance Comparison

Scaling factor	Image	*JBU*		*Proposed*	
		BPR (%)	**Time (sec.)**	**BPR (%)**	**Time (sec.)**
4	Cones	9.60	11.26	12.59	2.66
	Teddy	8.23	11.19	13.16	2.52
8	Cones	11.09	11.78	13.93	2.81
	Teddy	11.80	11.99	12.92	2.71

Table 1 also shows the processing time consumption comparison with JBU. We can find that our method is much faster than JBU. Therefore, the proposed method has better performance than JBU with respect to a tradeoff between upsampled depth image quality and computational complexity.

IV. Conclusion

In this paper, we proposed a depth image upsampling method using the Canny edge detector and JBU. It is an efficient method because it increases depth image resolution fast while protecting the edge information. Experimental results, showed that the proposed method showed high improvements in speed instead of some loss of quality of the depth image.

V. Acknowledgment

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VI. References

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