Frequency-based Bilateral Filter on Graphics Cards

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1. Introduction

- The bilateral filter performs edge-aware blurring. This is achieved by a range kernel that weighs the contribution of each pixel based on an intensity difference with the centre pixel:

$$BF[\mathbf{p}] = \frac{\sum_{\mathbf{q}\in\mathcal{S}} G_{\sigma_s}(||\mathbf{p}-\mathbf{q}||) R_{\sigma_r}(I_\mathbf{p} - I_\mathbf{q}) I_\mathbf{q}}{\sum_{\mathbf{q}\in\mathcal{S}} G_{\sigma_s}(||\mathbf{p}-\mathbf{q}||) R_{\sigma_r}(I_\mathbf{p} - I_\mathbf{q})}$$

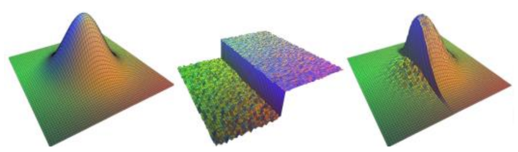

Figure 1: Illustrating the effect of the range kernel [1,2].

- The naïve implementation is quadratic due to the range kernel. Decomposing that using Fourier series leads to a sum of standard convolutions, which enables us to reduce the time complexity.

2. Prior work

- Piecewise-linear approach— Durand and Dorsey [2] propose filtering several images at different weights of the range kernel, then doing linear interpolation per pixel of the input.
- Bilateral grid—proposed data structure by Chen et al. [3] yielding a 3D array from a 2D image. The output is extracted by performing 3D convolution on the bilateral grid and slicing it.
- Previous literature on the Fourier BF looks either only at the Gaussian kernel or ones with similarly small tails [4], which disregards some like in [2].

3. Research Question

How to implement the frequency-based bilateral filter efficiently on a GPU?

- Subquestion: What are the effects of kernels with longer tails?
- Subquestion: What approach to choose for linear filtering?

4. Method

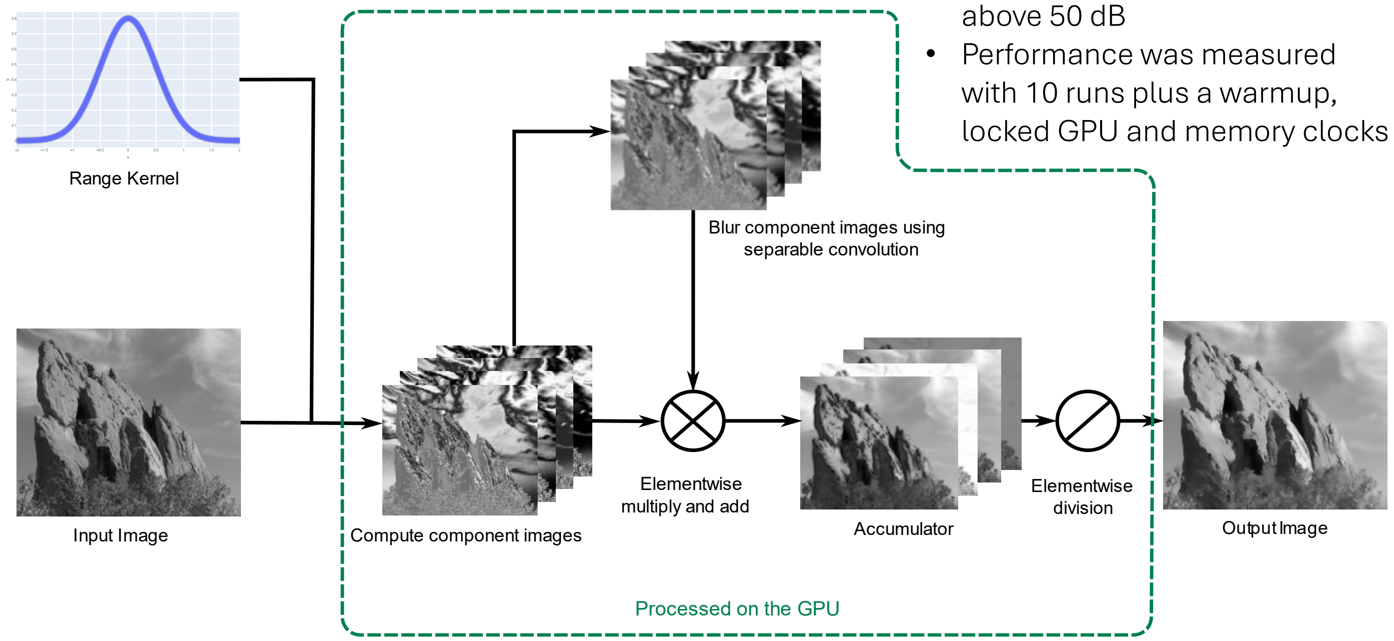

Figure 2: Diagram of the used algorithm

Evaluation:

- PSNR used to measure the accuracy of the filtering, goal: above 50 dB
- Performance was measured with 10 runs plus a warmup, locked GPU and memory clocks

5. Results

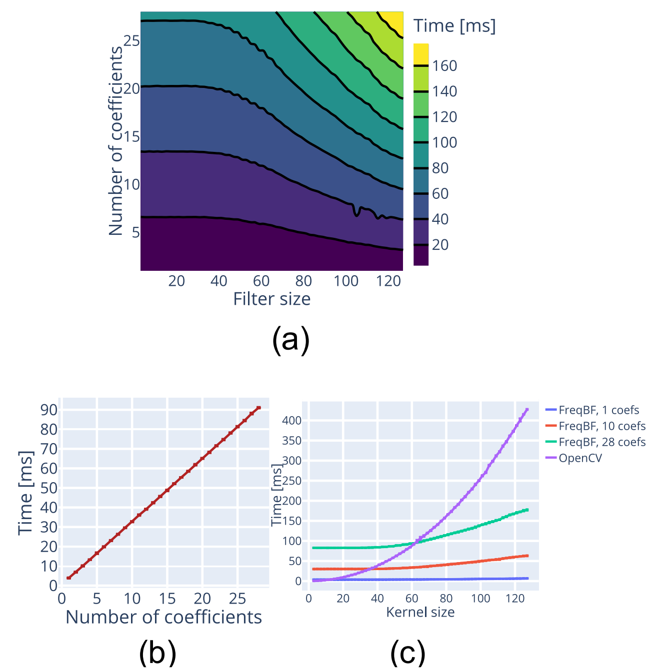

Figure 3: Frame times for filtering a 4500x3000 px image with varying filter sizes and varying number of coefficients (a), with the times for a kernel size of 127x127 shown in Figure 3b. Figure 3c compares the performance against the GPU-based bilateral filter available in OpenCV.

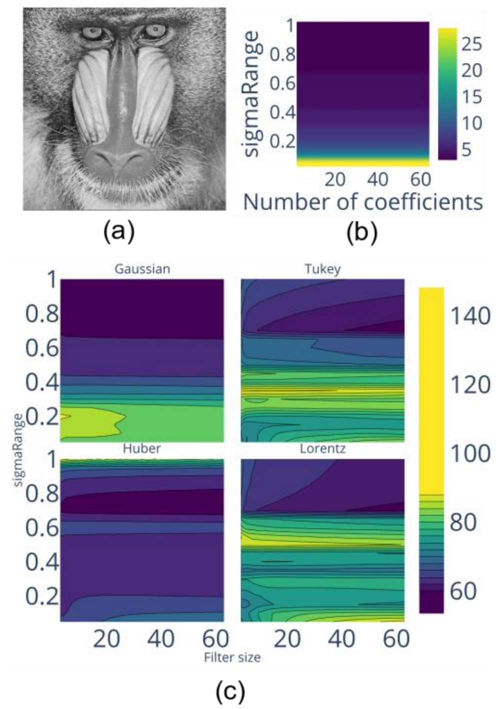

Figure 4: PSNR values (c) observed with the current metric for determining the number of coefficients (b) for the image presented in (a). With the current metric, the represented kernels show that unnecessarily many values are used for lower sigma-range values.

6. Limitations and Future Work

- Only separable convolutions were attempted – summed-area tables have efficient GPU implementations [5] that can benefit this filter's performance.
- Low sigma-range values get overcompensated – more robust way of determining the number of coefficients is needed.
- Only OpenCV was used as a baseline for performance measurements – a comparison against the bilateral grid [3] would be more interesting.
- The number of convolutions could be reduced in half [4].
- Half-precision floating-point could be used to increase memory throughput.

7. Conclusion

- Performance gains are achieved for large images and large spatial kernel sizes.
- More robust ways of determining the number of coefficients are needed due to kernels with longer tails

References

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