CURVATURE BASED BILATERAL FILTER

1. BACKGROUND

- Bilateral Filter - fast, edge-preserving, smoothing filter.
- Used in image denoising, tone mapping, low-light photography, etc.
- Uses distance and colour difference of neighbouring pixels.

- Trilateral Filter - Uses linear plane approximation to account for gradients in an image.

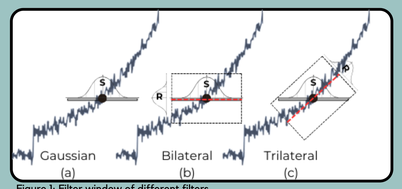

Figure 1: Filter window of different filters.

- Linear approximation is not always suitable. Can we improve it by accounting for curvature in the signal?

2. RESEARCH QUESTION

- *How can integration of local curvature approximation improve the bilateral filter for the distribution of pixel values?*

3. METHOD

- The idea is to reconstruct local curvature geometry from noisy input.
- It uses the Bilateral filter to approximate partial derivatives of the input.
- Approximate local geometry by fitting a **quadratic surface** through input using Taylor's second-order approximation.

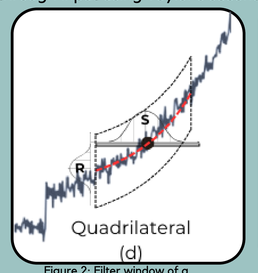

Figure 2: Filter window of a Quadrilateral filter.

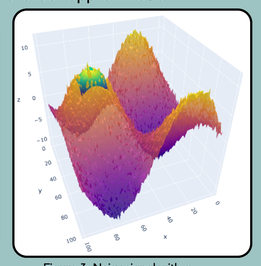
Figure 3: Noisy signal with a quadratic surface approximation.

- If the quadratic surface does not match the neighbouring pixels, we fall back on a simpler geometry approximation: the Bilateral filter.
- The closer the plane matches the neighbouring pixels, the better the approximation and the lower the **uncertainty** value.
- Uncertainty decides the level of interpolation with the Bilateral filter.

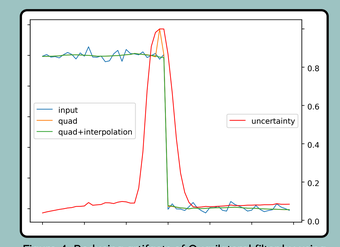

Figure 4: Reducing artifacts of Quarilateral filter by using interpolation with the Bilateral filter

4. RESULTS

1D

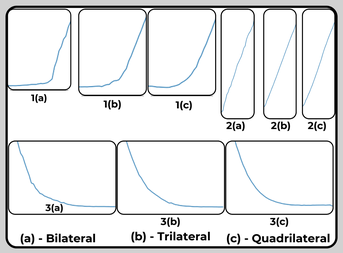

Figure 5: Performance of filters with noisy 1D signal.

- Bilateral filter struggles to remove noise in high gradient areas.
- Quadrilateral filter achieves an overall smoother result, especially in curved areas.

IMAGE

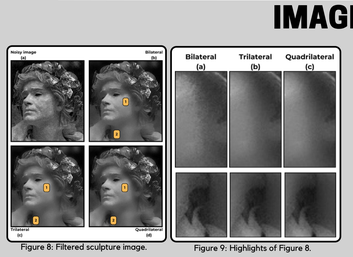

Figure 8: Filtered sculpture image.

Figure 9: Highlights of Figure 8.

- The Bilateral filter leaves the noise in gradient regions.
- Both Trilateral and Quadrilateral filters successfully remove the noise.

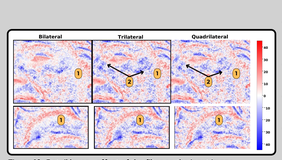

Figure 10: Detail layer - effect of the filter on the input image.

- (1) - White areas represent the filter not affecting the input image.
- The Bilateral fails to denoise in these areas.
- (2) - Patches of one color represent distortion of the image.
- Trilateral filter darkens originally bright areas due to poorer geometry approximation.

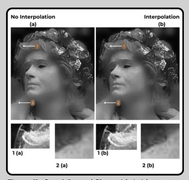

Figure 11: Quadrilateral filter with/without interpolation.

- Utilizing Interpolation with the Bilateral filter results in image with sharper edges.

2D

- Quadrilateral filter successfully removes noise from high gradient regions, achieving the smoothest result - Figure 6.
- The Quadrilateral filter distorts the original signal less than the Trilateral filter - Figure 7.

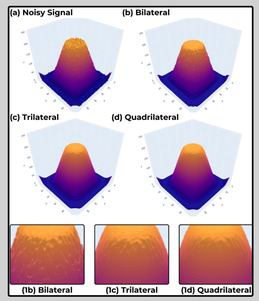

Figure 6: Performance of filters on a 2D signal.

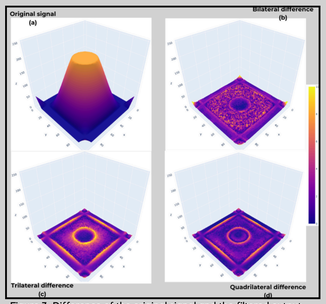

Figure 7: Difference of the original signal and the filtered output.

TONE-MAPPING

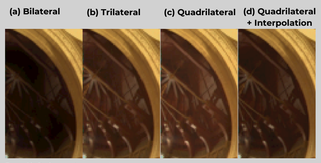

Figure 12: Dark areas tone-mapping.

- Quadrilateral filter produces higher contrast in dark regions.

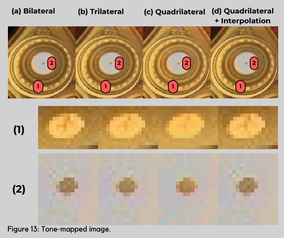

Figure 13: Tone-mapped image.

- Quadrilateral filter with interpolation produces:
  - Better detail preservation.
  - Brighter than the Bilateral's filter result.
  - Less halos

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5. FUTURE WORK

- Multi-stage interpolation process with Trilateral, Bilateral and Gaussian.
- Automatic parameter selection for uncertainty for better usability.
- Computational efficiency.

6. CONCLUSION

- Edge-preserving smoothing filter considering local curvature.
- Smoothing in high-gradient areas while preserving the original distribution of pixel intensities.
- Improved edge preservation by using interpolation with the Bilateral filter.
- Potential applications: multimedia analysis, denoising, tone-mapping and more.

7. REFERENCES

| [1] | C. Tomasi and R. Manduchi, "Bilateral filtering for gray and color images," 1998. |

| [2] | P. Choudhury and J. Tumblin, "The trilateral filter for high contrast images and meshes," in ACM SIGGRAPH 2005 Courses, 2005, p. 5–es. |