# QuaSI: Quantile Sparse Image Prior for Spatio-Temporal Denoising of Retinal OCT Data

Franziska Schirrmacher[1,*], Thomas Köhler[1,*], Lennart Husvogt[1], James G. Fujimoto[2], Joachim Hornegger[1], and Andreas K. Maier[1]

[1] Pattern Recognition Lab, Department of Computer Science, Friedrich-Alexander-Universität (FAU) Erlangen-Nürnberg

[2] Departement of Electrical Engineering & Computer Science and Research Laboratory of Electronics, Massachusetts Institute of Technology

[*] These authors contributed equally to this work.

## Introduction

- Optical Coherence Tomography (OCT) enables **3D imaging of retinal layers**
- Suffers from a low-signal-to-noise ratio due to **speckle noise**
- Development of a **spatio-temporal OCT denoising algorithm**
- Introduction of **quantile sparse image (QuaSI) prior** to reduce noise while preserving tiny morphological structures

## Materials and Methods

- **Quantile Sparse Image Prior:**

$$R_{\text{QuaSI}}(\mathbf{f}) = ||\mathbf{f} - Q(\mathbf{f})||_1$$

$\boldsymbol{f}$ B-Scan, $Q(\cdot)$ quantile filter

  - Result is fixed point under the quantile filter
  - For OCT denoising we use p = 0.5 quantile (median) filter
- **Optimization based approach:**
  - Energy minimization formulation:

$$\hat{\mathbf{f}} = \underset{\mathbf{f}}{\operatorname{argmin}} \sum_{k=1}^{K} \rho\left(\mathbf{f} - \mathbf{g}^{(k)}\right) + \mu \|\nabla \mathbf{f}\|_1 + \lambda R_{\text{QuaSI}}(\mathbf{f})$$

$\boldsymbol{g}^{(\boldsymbol{k})}, k \in [1, \dots, K]$ noisy input scans

$\rho(\cdot)$ huber loss function

  - **Linearization of the quantile filter** using a look-up table
  - **Alternating direction method of multipliers** and iteratively re-weighted least squares for optimization

## Experiments and Results

- Pig Eye Data:
  - Contains 35 eye positions with 13 B-scans each that are registered to each other
  - Results are evaluated using PSNR and SSIM relative to a goldstandard
- Clinical Data:
  - Contains data of 14 human subjects with two volumes each
  - Results are evaluated using mean-to-standard-deviation ratio (MSR) and contrast-to-noise ratio (CNR)
- Comparison to BM3D [1], Bayesian estimation denoising (BED) [2], averaging (AVG), and wavelet multi-frame denoising (WMF) [3]
- Quantitative results of the Pig Eye Data (see Fig.2)
- Algorithm achieves the **best denoising performance** on both datasets
- Descent tradeoff between noise reduction and structure preservation
- Code is available on our webpage:

**Contact**
✉ {franziska.schirrmacher,thomas.koehler}@fau.de
http://www5.cs.fau.de/en/research/software/idaa/

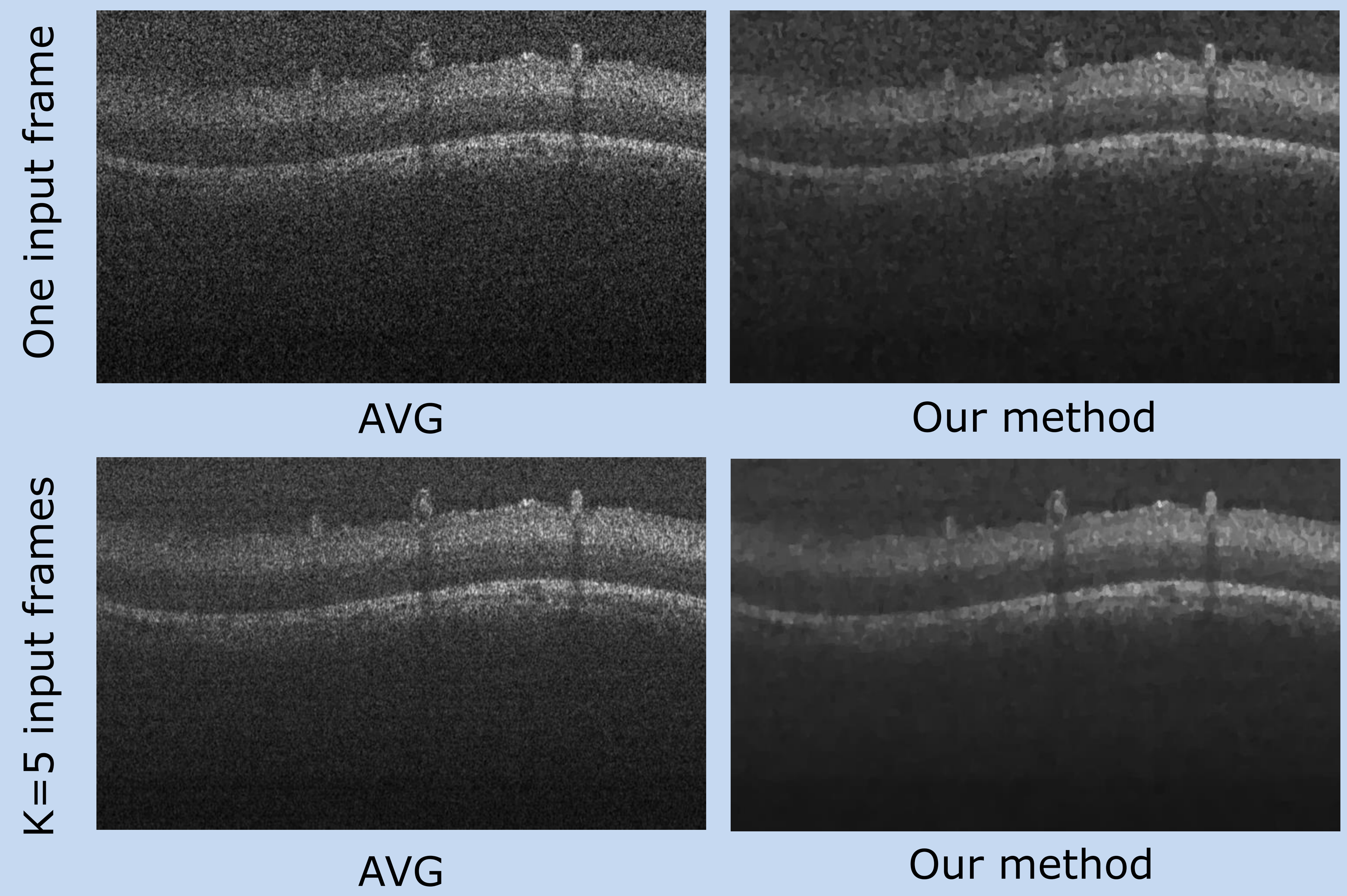


**Figure 1.** Comparison of our method against AVG for one and five input images

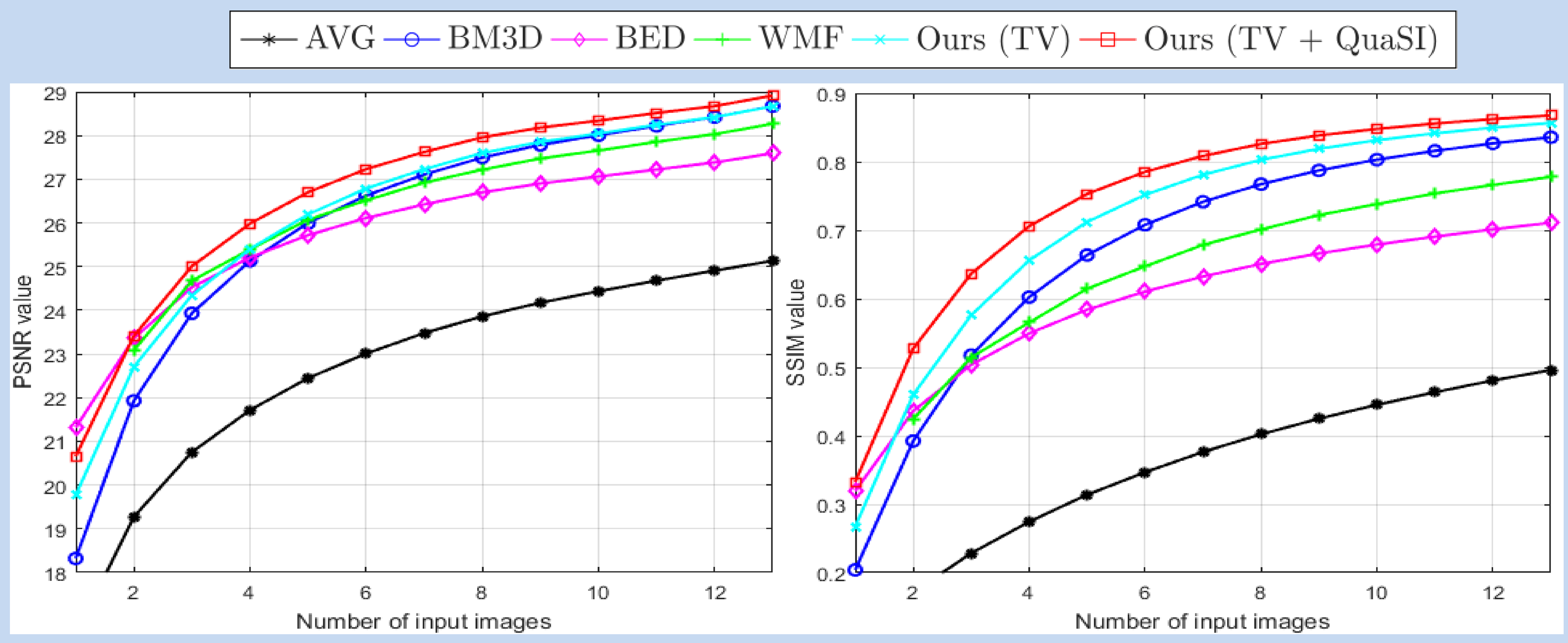


**Figure 2.** Mean PSNR and SSIM of different denoising methods on the pig eye dataset for different numbers of input images.

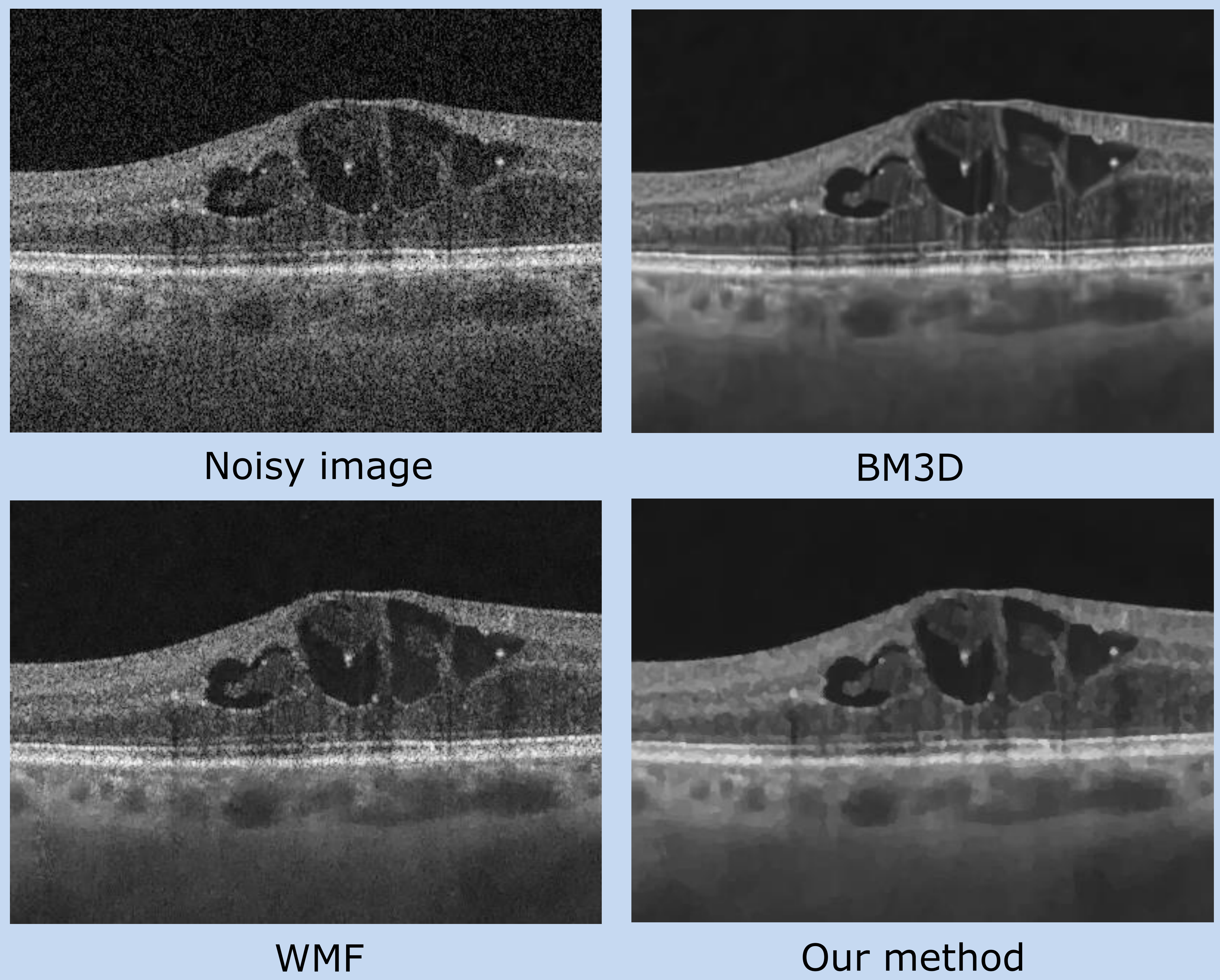


**Figure 3.** Denoising on the clinical dataset using K = 5 B-scans from a 46 years old male diabetic retinopathy patient

## Conclusion

- Spatio-temporal denoising algorithm for OCT data using the QuaSI prior
- More effective in reducing speckle noise compared to competing methods
- Future work: study the behavior of the QuaSI prior

## References

[1] Dabov K. et al.: Image Denoising by Sparse 3-D Transform-Domain Collaborative Filtering, IEEE Trans IP 16(8):145-149 (2007)

[2] Wong A. et al.: General Bayesian estimation for speckle noise reduction in optical coherence tomography retinal imagery, BOEx 18(8): 8338-8353 (2010)

[3] Mayer M. et al: Wavelet denoising of multiframe optical coherence tomography data., BOEx 3(3): 572 (2012)