Demonstration of Rapid Frequency Selective Reconstruction for Image Resolution Enhancement

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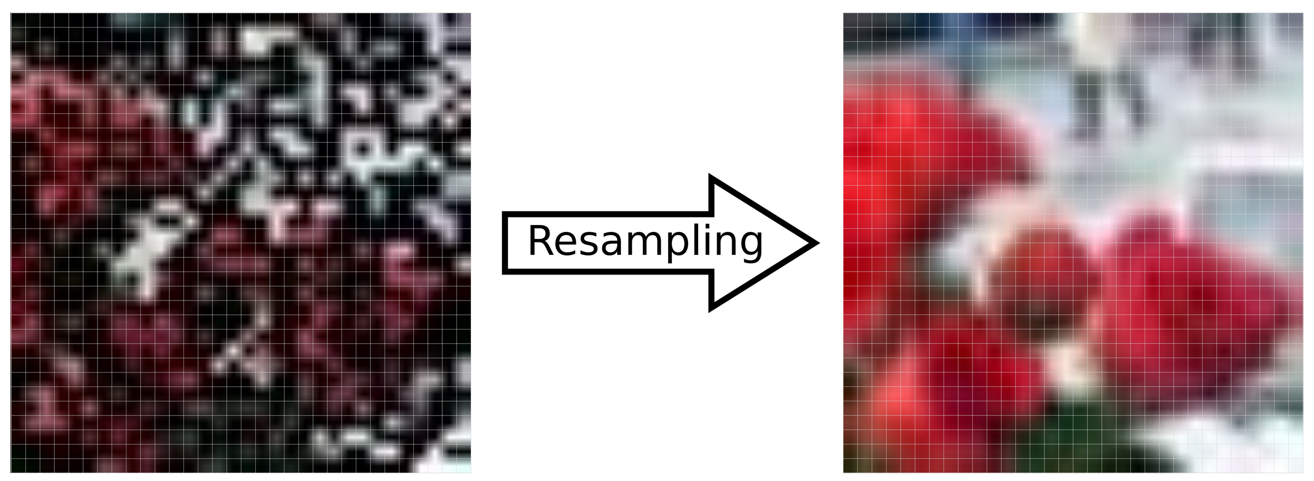
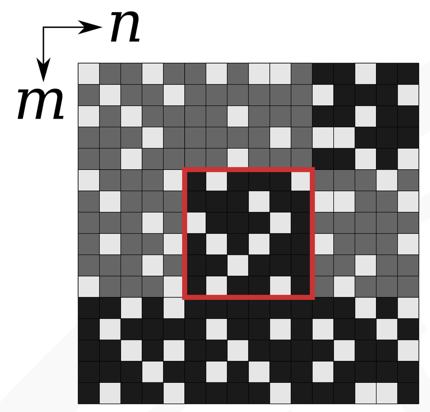
1. Motivation

- Many scenarios, where amplitude information of an image is not available on a regular, rectangular grid
  - Optical Cluster Eye
  - Micro-Optical Artificial Compound Eyes
  - Reducing visible influence of aliasing
  - Super-Resolution techniques [1]
- For further processing or displaying, a resampling to the full regular grid is required



2. Frequency Selective Reconstruction (FSR) [2]

- Iterative sparse model generation by superimposing weighted Fourier basis functions: $g[m,n] = \sum_{k \in \mathcal{K}} \hat{c}_k \varphi_k[m,n]$



- Spatial weighting function

$$w[m,n] = \begin{cases} \hat{\rho}^{\sqrt{\left(m-\frac{M-1}{2}\right)^2+\left(n-\frac{N-1}{2}\right)^2}} & , (m,n) \in \mathcal{A} \\ \delta\hat{\rho}^{\sqrt{\left(m-\frac{M-1}{2}\right)^2+\left(n-\frac{N-1}{2}\right)^2}} & , (m,n) \in \mathcal{R} \\ 0 & , (m,n) \in \mathcal{B}_i \cup \mathcal{B}_o \end{cases}$$

- Fixed frequency prior to favor low frequencies

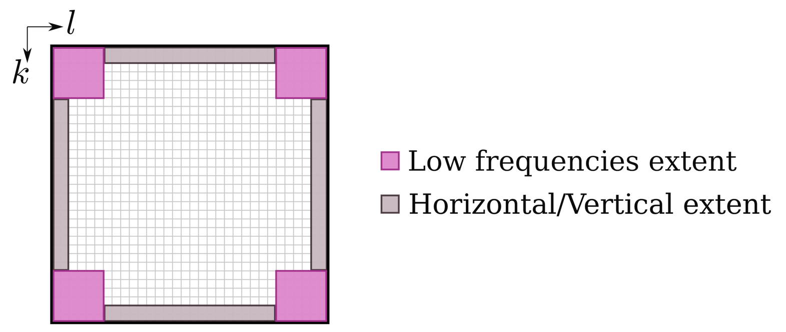
$$w_f[k,l] = \left(1 - \sqrt{2}\sqrt{\frac{\tilde{k}^2}{M^2} + \frac{\tilde{l}^2}{N^2}}\right)^2$$

→ Approximation of the Optical Transfer Function
→ Improved reconstruction quality

3. Demonstration

Algorithmic Enhancements

- YUV color space dependent reconstruction [3]
  - Linear interpolation for chroma channels
  - FSR for luminance channel only
- Limit number of selected basis functions [4]
- Restrict set of possible basis functions [4]



Software Optimizations

- C++ implementation using FFTW3 library
- Parallelization using OpenMP pragmas to make use of all processor cores
- Vectorization
  - Manual preparation of loops
    → Avoid control flows
  - GCC's autovectorization features and OpenMP's SIMD pragmas

Test Systems

Notebook	
CPU	i7-6700HQ
Speed	2.60 GHz
Cores	4
RAM	8 GB
Xeon	
CPU	2 × Xeon E5-2630v4
Speed	2.20 GHz
Cores	2 × 10
RAM	32 GB

4. Conclusion

Reconstruction quality in dB PSNR for different subsampling densities (TECNICK)

	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%
FSR	**27.03**	**29.69**	**32.83**	**34.94**	**36.66**	**38.23**	**39.79**	**41.50**	**43.59**	**46.75**	**49.55**
SKR	16.69	28.11	31.81	33.23	34.29	35.30	36.41	37.75	39.55	42.55	45.42
CLS	24.82	26.94	29.85	32.06	34.03	35.92	37.87	40.01	42.58	46.28	49.37
SI	24.30	27.17	30.87	33.31	35.33	37.16	38.98	40.93	43.23	46.60	49.46

SKR: Steering Kernel Regression, CLS: Constrained Split Augmented Lagrangian Shrinkage Algorithm, SI: Sparse Wavelet Inpainting

- FSR well suited for image reconstruction problems
- Visually noticeable gains of several dB PSNR compared to other state-of-the-art algorithms
- Acceleration of the reconstruction process by
  → Exploiting YUV color space properties
  → Reducing the number of basis functions
  → Estimating the required set of basis functions
  → Software optimizations

Accelerated reconstruction process:
→ 2 - 4 fps using test system Notebook
→ 5 - 11 fps for test system Xeon

References

[1] M. Schöberl, J. Seiler, S. Foessel, and A. Kaup, "Increasing imaging resolution by covering your sensor," in *Proc. IEEE International Conference on Image Processing*, Brussels, Belgium, Sep. 2011, pp. 1937–1940.

[2] J. Seiler, M. Jonscher, M. Schöberl, and A. Kaup, "Resampling images to a regular grid from a non-regular subset of pixel positions using frequency selective reconstruction," *IEEE Transactions on Image Processing*, vol. 24, no. 11, pp. 4540–4555, Nov. 2015.

[3] M. Bätz, A. Eichenseer, M. Jonscher, J. Seiler, and A. Kaup, "Accelerated hybrid image reconstruction for non-regular sampling color sensors," in *Proc. IEEE International Conference on Visual Communications and Image Processing (VCIP)*, Dec. 2014, pp. 217–220.

[4] N. Genser, J. Seiler, and A. Kaup, "Local statistics estimation for rapid frequency selective extrapolation," in *Proc. 2017 International Conference on Systems, Signals and Image Processing (IWSSIP)*, May 2017, pp. 1–5.