Joint Denoising and Demosaicking of RAW Video Sequences

Antoni Buades and Joan Duran

Dept. Mathematics and Computer Science & IAC3. Universitat de les Illes Balears, E-07122, Palma, Spain

toni.buades@uib.es, joan.duran@uib.es

1. Introduction

The demosaicking provokes the spatial and color correlation of noise, which is afterwards enhanced by the imaging pipeline. We present a novel joint denoising and demosaicking algorithm for videos that uses a 3D motion-compensated distance to select similar patches [1]. Although all pixels are modified, only original values are considered for averaging. This average further depends on a 2D similarity distance to avoid occlusions effects.

2. Motion-Compensated Interpolation of Grayscale Videos

Let $\{\tilde{f}_n\}_{n=1}^N$ be an initially interpolated grayscale video and D a mask keeping the trace of the original values. We describe the algorithm for the n_u-th frame, $n_u \in \{1, \ldots, N\}$.

- TV-L1 optical flow [2] is used to get $\{v_n\}_{n=1}^N$, the motion fields between $\tilde{f}_{n_u}$ and $\tilde{f}_n$.
- The algorithm proceeds patch per patch of $\tilde{f}_{n_u}$ by computing

$$u(P) = \frac{1}{C_P} \cdot \sum_{P_n^k \in \mathcal{N}_P} \omega\big(\tilde{f}_{n_u}(P), \tilde{f}_n(P_n^k)\big) D(P_n^k) \cdot \tilde{f}_n(P_n^k),$$

  where ω measures the patch similarity and C_P is a normalization factor.
- The selection of patches in $\mathcal{N}_P$ depends on a **motion-compensated 3D distance**, which is **robust to noise and aliasing artifacts**. For each reference patch P in $\tilde{f}_{n_u}$, let $\mathcal{P} = \bigcup_{n=1}^N (P + v_n(P))$ be its extension along the frame dimension. We look for the K extended patches $\mathcal{Q}$ minimizing

$$d(\mathcal{P}, \mathcal{Q}) = \sum_{n=1}^N \|\tilde{f}_n(P + v_n(P)) - \tilde{f}_n(Q + v_n(Q))\|^2.$$

  Therefore, the selected group contains $K \cdot N$ 2D patches:

$$\mathcal{N}_P = \left\{ P_n^k \mid P_n^k = P^k + v_n(P^k),\ 1 \leq n \leq N,\ 1 \leq k \leq K \right\}.$$

- The weights are finally defined in terms of a **2D similarity distance**:

$$\omega\big(\tilde{f}_{n_u}(P), \tilde{f}_n(P_n^k)\big) = \exp\left(- \frac{\|\tilde{f}_{n_u}(P) - \tilde{f}_n(P_n^k)\|^2}{h^2} \right),$$

  which makes the algorithm **robust to occlusions and flow inaccuracies**.
- Each pixel value is estimated by aggregation of the patches containing it.

3. Video Demosaicking Method with Noise Removal

The algorithm for denoising and demosaicking of videos consists in the following steps:

i) Apply the local directional demosaicking method in [3, Section II] to each frame to get the initial demosaiced video sequence $\{\tilde{\mathbf{f}}_n = (\tilde{f}_n^R, \tilde{f}_n^G, \tilde{f}_n^B)\}_{n=1}^N$.

ii) Compute the motion fields $\{v_n\}_{n=1}^N$ on $\{\tilde{f}_n^G\}_{n=1}^N$.

iii) Update the green channels by applying the strategy from Section 2 to $\{\tilde{f}_n^G\}_{n=1}^N$, with D being the Bayer CFA of the green. Let $\{u_n^G\}_{n=1}^N$ be the updated sequence.

iv) Apply the method from Section 2 to the **channel differences** $\{\tilde{f}_n^R - u_n^G\}_{n=1}^N$. The Bayer CFA of the red is used as mask D and the patch-based distances $\|\cdot\|$ are computed on $\{u_n^G\}_{n=1}^N$. Add back the green values to get the final red sequence.

v) Repeat the process in (iv) for the blue sequence.

The interpolation method removes the noise of the green and of the channel differences. Since the updated noise-free green is finally added back, we obtain a **noise-free video**.

3. Experimental Results

Results on simulated noisy CFA sequences

We compare with the single-image demosaicking (SID) algorithm in [3] and the method resulting from concatenating temporal demosaicking (TD) [4] with VBM3D denoising [5].

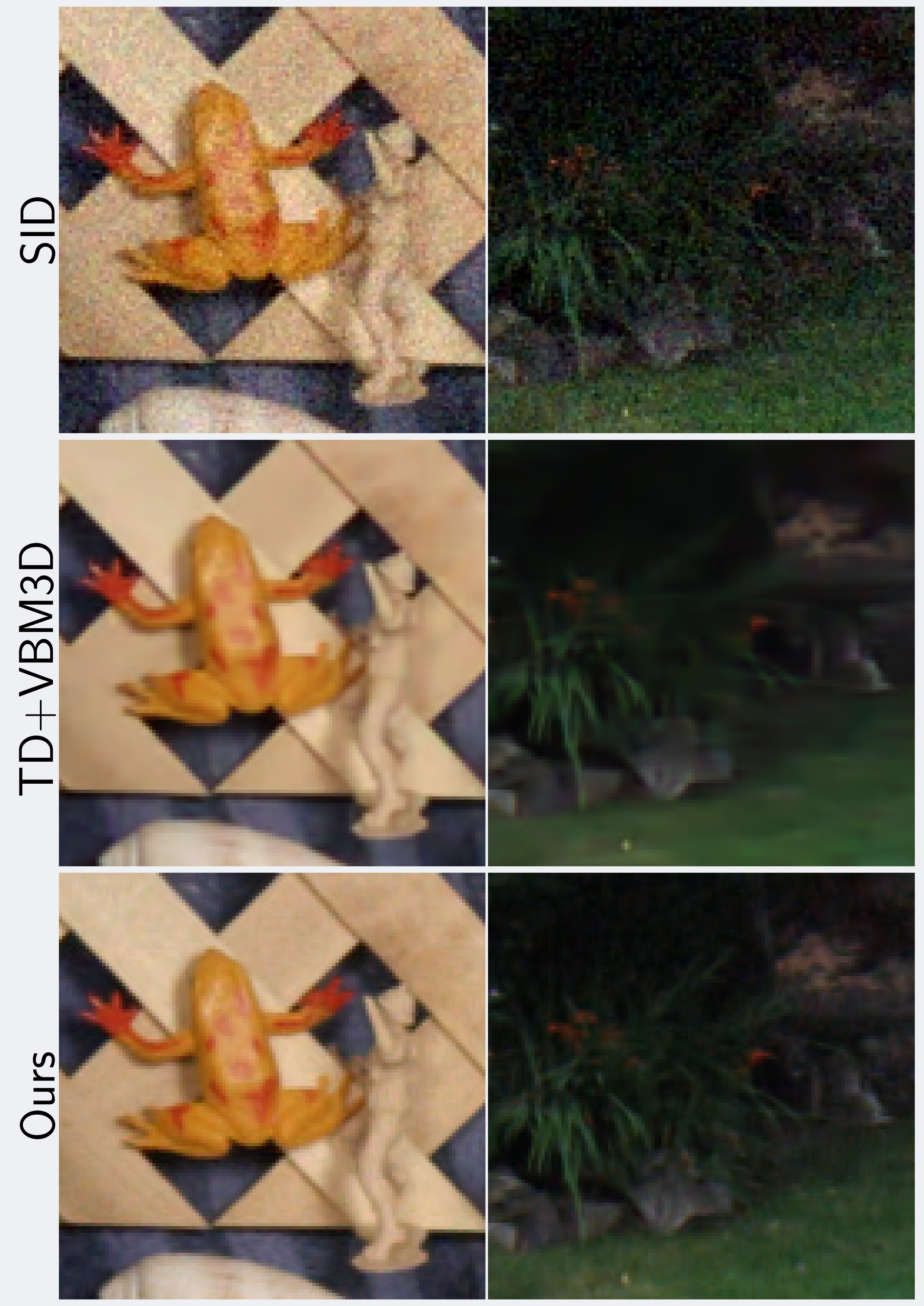
Central view of 8-frames dataset.

Image	SID	TD+VBM3D	Ours
Army	5.39	3.55	3.07
Art	4.98	3.36	3.23
Dog	5.14	8.08	8.19
Books	9.31	3.48	3.48
Avg.	6.21	4.61	**4.49**

RMSE for each central view and noise s.d. $\sigma = 5$.

Image	SID	TD+VBM3D	Ours
Army	9.50	4.62	4.42
Art	9.30	5.01	4.85
Dog	9.54	8.69	8.71
Books	12.21	5.06	5.18
Avg.	10.14	5.85	**5.79**

RMSE for each central view and noise s.d. $\sigma = 10$.



SID does not remove any noise, while the results by TD+VBM3D are slightly blurry and many details have been removed. The proposed algorithm correctly suppresses demosaicking artifacts and noise.

Results on real RAW sequences

For each pair: left picture is the original RAW frame after single-image demosaicking by [6] and the right picture is our result. In both cases, we applied the imaging pipeline from [6] after the demosaicking. Notice in the non-processed images the spatially and colored correlated noise, which is correctly removed with the proposed approach.

4. Conclusions

We have introduced a single algorithm to deal with denoising and demosaicking of RAW videos. The proposed approach, based on patch averaging, avoids the creation of artifacts and colored spots in the final sequence, outperforming the combination of more complex video denoising and demosaicking methods.

5. References

[1] A. Buades and J. Duran, "Flow-based video super-resolution with spatio-temporal patch similarity," in *Proc. British Mach. Vis. Conf. (BMVC)*, London, UK, 2017, pp. 656.1–656.12.

[2] C. Zach, T. Pock, and H. Bischof, "A duality based approach for realtime TV-L1 optical flow," in *Proc. DAGM Symp.*, Heidelberg, Germany, 2007, vol. 4713 of *LNCS*, pp. 214–223.

[3] J. Duran and A. Buades, "Self-similarity and spectral correlation adaptive algorithm for color demosaicking," *IEEE Trans. Image Process.*, vol. 23, no. 9, pp. 4031–4040, 2014.

[4] X. Wu and L. Zhang, "Temporal color video demosaicking via motion estimation and data fusion," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 16, no. 2, pp. 231–240, 2006.

[5] K. Dabov, A. Foi, and K. Egiazarian, "Video denoising by sparse 3D transform-domain collaborative filtering," in *Proc. 15th European Signal Processing Conference*, Poznan, Poland, 2007, pp. 145–149.

[6] S. Andriani, H. Brendel, T. Seybold, and J. Goldstone, "Beyond the KODAK image set: a new reference set of color image sequences," in *Proc. IEEE Int. Conf. Image Process. (ICIP)*, Melbourne, Australia 2013, pp. 2289–2293.

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