ML-SIM: Reconstruction of structured illumination microscopy images using deep residual neural networks

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Structured illumination microscopy (SIM) has become an important technique in optical super-resolution microscopy. One reason for this is that SIM allows a doubling of resolution, while being sufficiently fast to be live-cell compatible. However, the reconstruction of SIM images is often met with great difficulties causing the resulting image qualities to suffer. This becomes more prominent for images with low signal-to-noise ratios, where traditional methods will mistakenly treat noise as signal and reconstruct it into artefacts that can sometimes be hard to distinguish from real features in the sample. Here we propose a versatile reconstruction method for SIM reconstruction, ML-SIM, using machine learning. The model is an end-to-end deep residual neural network that is trained to be free of characteristic SIM artefacts, while being robust to noise and irregularities in the illumination patterns of the raw SIM input frames. This is possible by using an approach to model training, where the training data is generated by simulation of the SIM imaging process. Simulating the data provides ideal targets (ground truths) for supervised learning, which let the model strive to surpass traditional reconstruction methods during training. Although the training data is simulated and unrelated to microscopic samples, we find that the model generalises well and can be applied to experimental data from two distinct SIM microscopes. The reconstruction quality enabled by our method is compared with traditional SIM reconstruction methods [1-3], and we demonstrate advantages in terms of noise, artefacts and contrast for both simulated and experimental inputs.

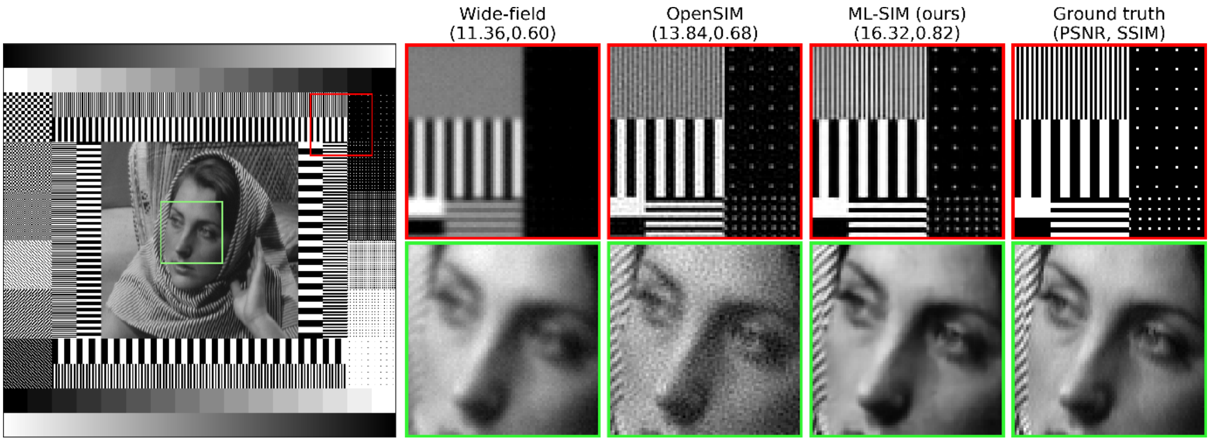

Figure 1: Reconstruction of a simulated input represented here as a wide-field image. The output of our method ML-SIM is compared with that of a traditional reconstruction method OpenSIM [3]. The metrics shown are the peak signal-to-noise ratio [dB] and structural similarity index.

References

[1] K. Wicker et al., "Phase optimisation for structured illumination microscopy", Opt. Express (2013).
[2] M. Müller et al., "Open-source image reconstruction of super-resolution […]", Nat. Comm. (2016).
[3] A. Lal et al., "Structured illumination microscopy image reconstruction algorithm", IEEE (2016).