High-resolution retinal imaging by corneal immersion

Nizan Meitav,[1] E. N. Ribak,[1] and A. V. Goncharov[2]

[1]Department of Physics, Technion – Israel Institute of Technology

[2]Applied Optics Group, Department of Experimental Physics, National University of Ireland, Galway

Abstract: Imaging the retina at high resolution requires a dilated pupil, which in turn results with exposure of more corneal irregularities than in a smaller pupil. We developed an imaging technique which diminishes the optical power of the cornea by refractive index matching [1]. By using lens-fitted goggles for saline solution immersion, we reduced the aberrations of the cornea and improved the retinal image quality (since most aberrations are caused by the cornea). This immersion technique can be integrated with other methods of retinal imaging for further improvements of their spatial resolution, or relaxing requirements for ocular aberration correction.

Model: The attenuation of the anterior corneal aberration by immersion can be modeled by a corrugated phase plate $\kappa(x, y)$. In general, we consider light propagating through a constant path T, part of it through a medium of refractive index n_1, another part through another medium of a different refractive index n_2, separated by the variable boundary $\kappa(x, y)$.

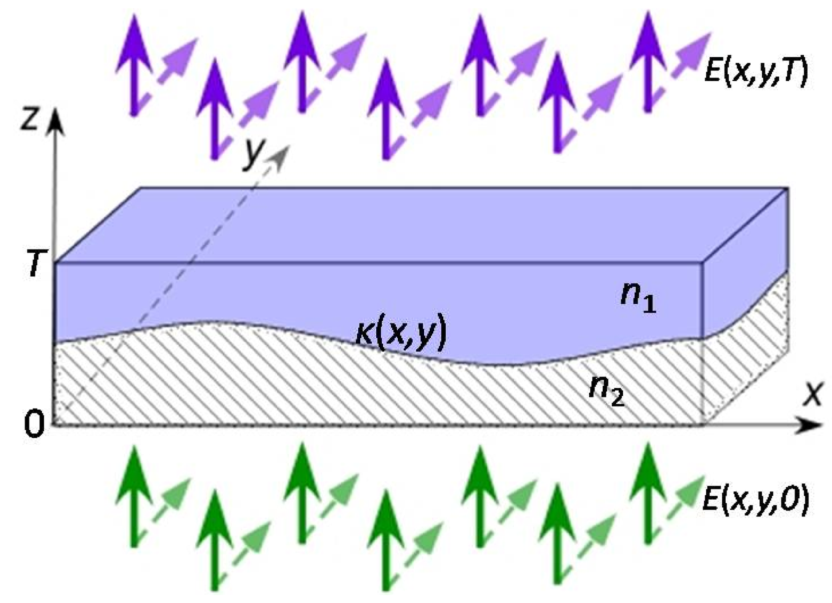


Fig 1. Electromagnetic wave **E** crossing successively through two different media with a curved boundary between them. In general, the wave front can take any shape, and we ask how is it modified by changing one of the refractive indices.

The wave front error can be expressed as the sum of the optical thicknesses of the two media:

$$\phi(x,y;z=T)=n_1\left[T-\kappa(x,y)\right]+n_2\kappa(x,y)=n_1T+\Delta n\kappa(x,y)$$

By using saline solution we reduce $\Delta n=n_2-n_1$ to 1/10 of an air-cornea interface, with the corneal wave front error also reduced respectively.

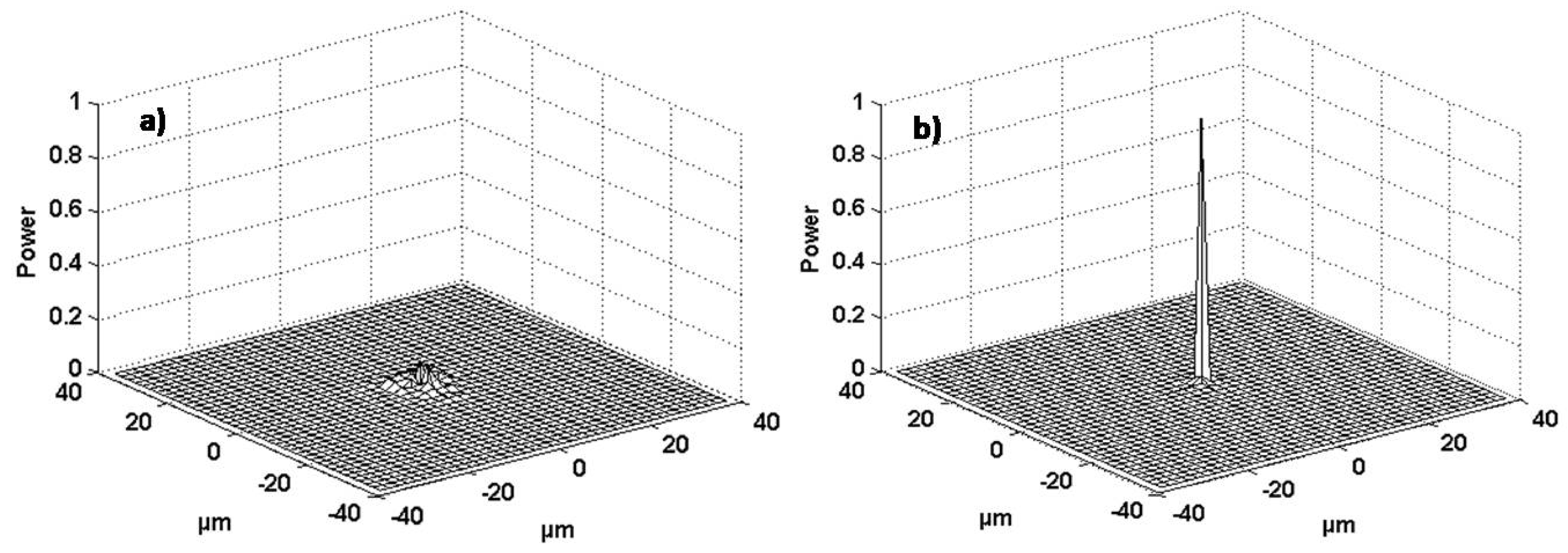


Fig. 2. The PSF of the average cornea without immersion (a) and with immersion (b). The PSFs were calculated by averaging Zernike coefficients measured from 228 eyes. Both PSFs were normalized by the maximal value of the PSF with immersion.

Effect of immersion on the point spread function of the whole eye

By reducing the optical power of the cornea we also reduce the cornea-lens spherical aberration compensation mechanism. Therefore the PSF of the immersed eye is reduced compared to the one without immersion. Using an eye model, we designed an aspheric plate to correct most of the residual spherical aberrations by 0.187 μm [2].

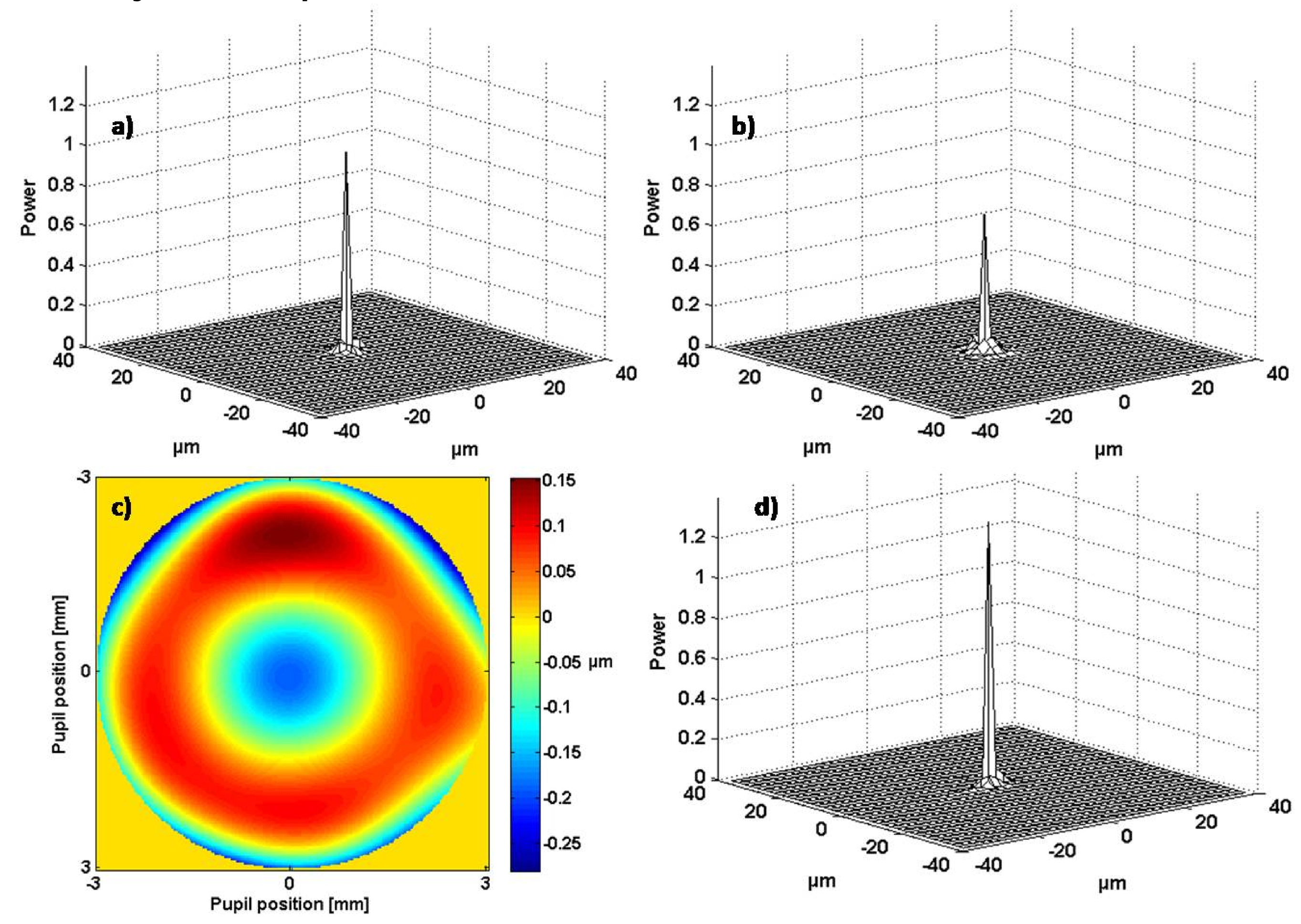
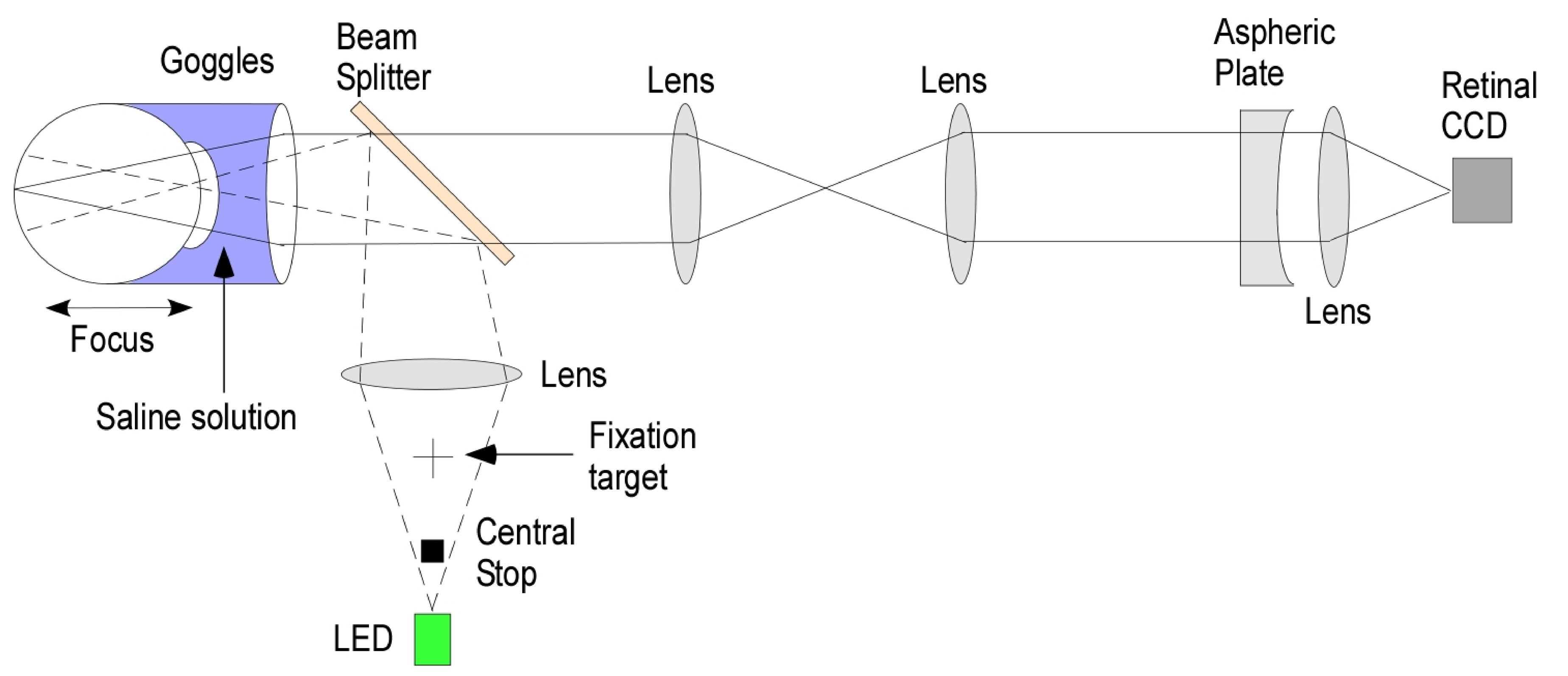


Fig. 3. Averaged PSF of a whole eye without immersion (a), compared to average eye with corneal immersion (b). The degradation using immersion is mostly caused by spherical aberration of the crystalline lens, as is evident from the corresponding wave front error map (c). By correcting this static spherical aberration by an aspheric plate, the PSF of the immersion setup is improved (d). The PSF of the complete eye was calculated by the averaged Zernike coefficients measured on 532 eyes. All PSFs were normalized by the maximal value of Fig 3(a).

Immersion setup



Retinal images analysis: results have been compared to parallel setup (direct imaging, i.e. without immersion and aspheric plate). In both setups, resolution was improved by iterative weighted shift-and-add, which allows us to oversample a large batch of shifted images [3].

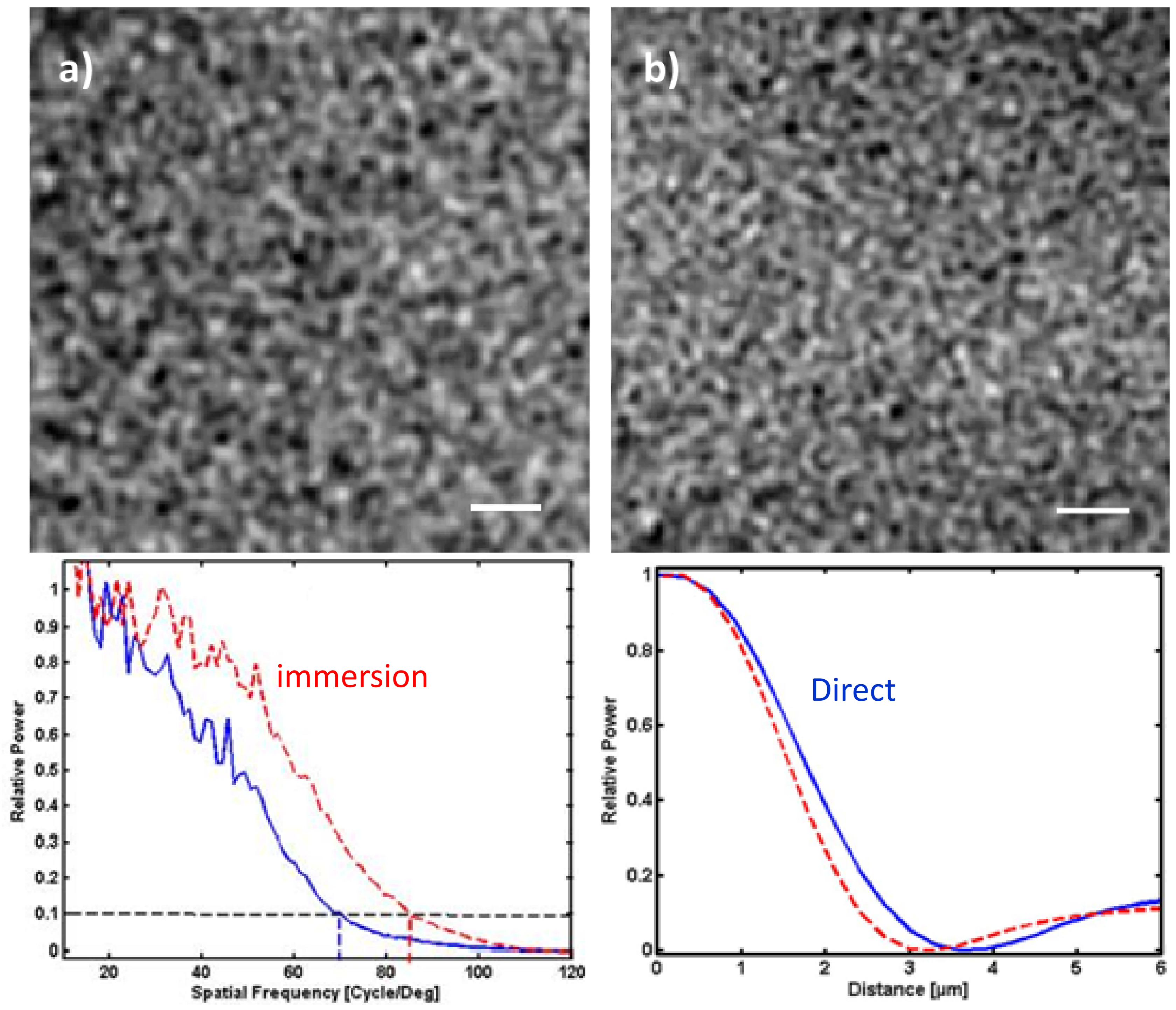


Fig. 4. (Top row) Retinal image comparison between direct imaging (left) and immersion imaging (right) for the same subject. The resolution of both images have been improved by weighted shift and add [1]. Scale bar 25 μm. (Bottom left) Comparison between the radial power spectra of the two setups. (Bottom right) Comparison of the point spread function estimation of the two setups [4].

Advantages of immersion:

- Removal of all but one tenth of the corneal aberrations.
- Reduction of tear film variable aberrations.
- Immersion helps in cases of subjects with strong lower-order aberrations, such as astigmatism, or in keratoconus.
- Reduction of the corneal reflection, which shifts with saccades and is therefore hard to dispose of.

References:

1. N. Meitav, E. N. Ribak and A. V. Goncharov, *"High-resolution retinal imaging by corneal immersion,"* Submitted (2011).
2. A. V. Goncharov and C. Dainty, "*Wide-field schematic eye models with gradient-index lens*," J. Opt. Soc. Am. A **24**, 2157-2174 (2007).
3. N. Meitav and E. N. Ribak, "*Improving retinal image resolution with iterative weighted shift-and-add*," J. Opt. Soc. Am. A **28**, 1395-1402 (2011).
4. N. Meitav and E. N. Ribak, "*Estimation of the ocular point spread function by retina modeling*," Opt. Lett. **37**, 1466-8 (2012).