HYBRID PHASE IMAGING USING THE TRANSPORT OF INTENSITY EQUATION AUGMENTED WITH WAVEFRONT SENSING DATA

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The transport-of-intensity equation (TIE) method extracts a phase image from the axial derivative of transverse intensity[1]. Since effectively only the divergence of the flux—equal to the Laplacian of the phase under uniform intensity—is measured, TIE methods often suffer from low frequency artifacts and are unable to measure linear phase ramps. While strong regularization[2] and structured illumination[3] have been used to overcome these problems, we instead propose a novel method whereby we augment the TIE approach with wavefront sensing (WFS). Unlike TIE, wavefront sensing instead has excellent low frequency performance but poor high frequency performance; combining the two approaches yields the best of both worlds. Mathematically, we seek a φ that minimizes $f(\phi) = \|d - T\phi\|^2 + \mu \|L(\phi_{WFS} - \phi)\|^2$, where φ is the phase, d is the intensity derivative from the TIE measurements, T is the TIE forward operator, L is a low pass operator and $\phi_{WFS}$ is the phase obtained via wavefront sensing. $\mu$ determines how strongly the solution’s low frequency components should agree with the low frequency components of the wavefront sensing solution, and $\mu = 0$ is equivalent to classic TIE.

We demonstrate our approach by reconstructing the phase of a phantom using simulated noisy TIE and WFS data, and the results are shown in the figure below. The phantom is 0.63 mm on a side, with 10 µm sampling intervals along each axis, while the wavefront sensor employs 150 µm pitch square lenses with effective focal length 5.1 mm. A wavelength of 540 nm was used for the simulation.

Figure 1: The phase phantom (a) consists of a circular region with parabolic profile riding on a Gaussian function centered at the lower left corner. TIE alone (b) misses the ramp of the Gaussian, while wavefront sensing misses high frequency details (c). Our hybrid approach yields a good compromise (d). Units are in mm, and contours denote $\pi/4$ intervals in the phase.