ENGINEERING THE PUPIL PHASE TO IMPROVE THE QUALITY OF DIGITALLY RESTORED IMAGES

S. Prasad[a], **V. P. Pauca**[b], **R. Plemmons**[b], **T. Torgersen**[b], and **J. van der Gracht**[c]

[a]Center for Advanced Studies
University of New Mexico
Albuquerque, New Mexico 87131
sprasad@unm.edu

[b]Department of Computer Science
Wake Forest University
Winston-Salem, North Carolina 27109

[c]Holospex, Inc.
6470 Freetown Rd., Suite 200-104
Columbia, Maryland 21044

We present extensions of the original proposal of Dowski and Cathey[1] on the use of a cubic pupil phase mask to optically encode a 3-dimensional object which can then be digitally restored to exhibit excellent depth-dependent detail. The main advantage of the proposed integrated optical-digital approach is that no penalty to either the total light flux or the spatial bandwidth of the imaging system is incurred, and excellent resolution and sensitivity are thus, in principle, achievable.

Our approach, which we call pupil phase engineering (PPE), is based on the mathematical theory of nonlinear optimization. Specifically, we propose to optimize the pupil phase profile by requiring that the competing demands of high fidelity of imaging coupled with excellent space invariance of the pupil-phase-enhanced blurring are simultaneously met. Both these requirements are necessary for reliable digital restoration of the phase-encoded image.

Previously,[2] we used the Strehl ratio (SR) as a metric of performance of such integrated optical-digital imaging systems. In this approach, we choose the pupil phase profile in such a way that the first few derivatives of the SR with respect to the defocus parameter are rendered small without degrading its actual value greatly. Our second PPE approach[3] implements the full point spread function (PSF), not just its on-axis value that defines the SR, in an optimization metric that is based formally on the concept of Fisher information (FI) used in statistical estimation theory. The FI furnishes a particularly simple measure of focus independence.

In the talk, we will elaborate further on both of our PPE approaches by presenting results of extensive numerical simulation. Although the current work is limited to the problem of focus extension, the PPE concept is more general, and can be employed for a number of other useful applications that range from static aberration control to a reduction of focal depth.

References

[1] E. Dowski and W.T. Cathey, "Extended depth of field through wavefront coding," *Applied Optics*, v. 34, p. 1859-1866, 1995.
[2] S. Prasad, T. Torgersen, V.P. Pauca, and R. Plemmons, "Integrated Optics Systems for Image Quality Control," *Proc. 2002 AMOS Technical Conference, Maui, HI, Sep 2002*, available on CD-ROM.
[3] S. Prasad, T. Torgersen, V.P. Pauca, R. Plemmons, and J. van der Gracht, " Engineering the Pupil Phase to Improve Image Quality," *Proc. Visual Information Processing XII, SPIE AeroSense Symposium, Orlando, FL, April 2003*, to be published.