Extended wavefront sensing with novel diversity functions

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Outline

- Introduction
  - Brief overview of phase diversity wavefront sensing using a distorted diffraction grating.
- Generalised Phase Diversity (GPD)
  - Basic principles for operation of a null sensor
- Extending GPD to full wavefront sensing
  - The Small Angle Expansion (SAE).
  - Preliminary experimental results and problems
- Applications and suggestions for future work
- Conclusions

Basic Background

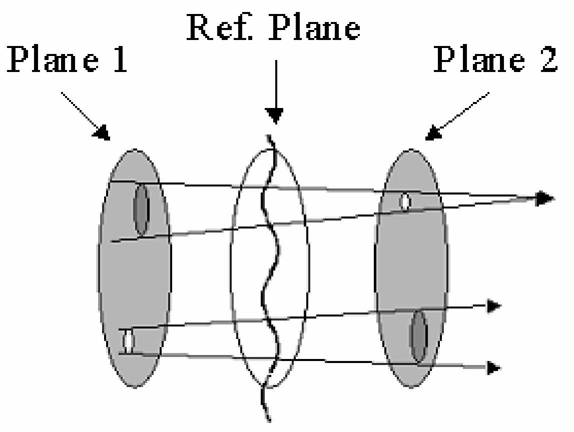


Figure 1: Shows the relationship between intensity and curvature

$$-\frac{k}{I}\frac{\partial I}{\partial z} = \nabla^2 \varphi \quad \text{I.T.E}$$

- Two-defocus method.
- Wavefront curvature is related to axial intensity derivative.
- Phase retrieval using ITE and Green's function solution [1].
- Problem: limiting assumptions placed on the wavefront

PD with Diffractive Optics

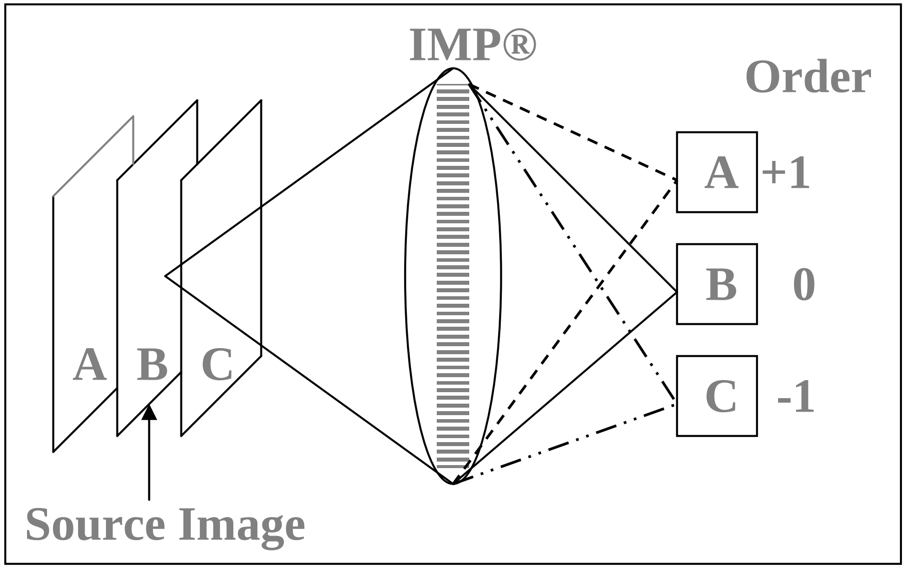


Figure 2: Shows the design of the current wavefront sensor.

- Quadratically distorted defocus grating.
- Images of different object layers are recorded on the same focal plane [2].
- The plane separation and image locations are determined by the properties of the grating.

Note: IMP® is a DERA (now QinetiQ) trademark

Generalised Phase Diversity

- Requires two intensity images each convolved with different, but related, aberration functions (in a DOE).
- For a null sensor we restrict the permitted functions to ones which satisfy the necessary and sufficient conditions [3]:
  - must provide a null output for plane wavefronts, and an error signal for distorted wavefronts.
  - Filter function must be complex with ‘same symmetry’

Extension to full wavefront sensing

- Requires a new algorithm to solve for the unknown phase which:
  - Doesn’t depend on the Intensity Transport Equation.
  - Can be used with any (allowable) diversity function – including defocus!
  - Uses the error signal defined in our previous publications….

The Error Signal

- Formed by the difference between the intensity images in the ±1 diffraction orders.

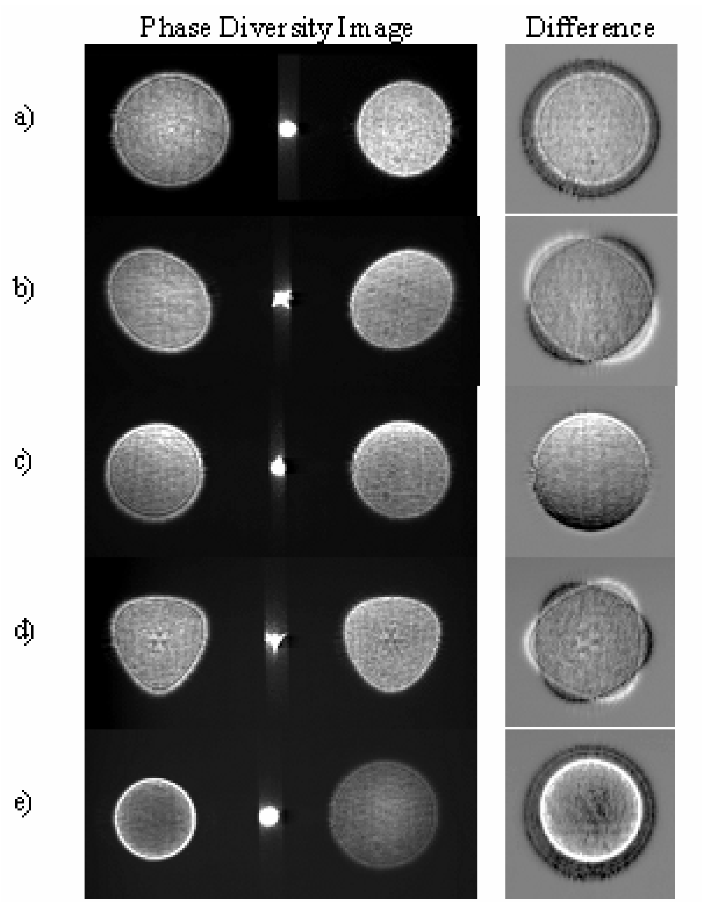
$$d(r) = j_+(r) - j_-(r)$$

$$\frac{\mathrm{d}(r)}{2i} = \int d\xi\, \mathrm{H}(\xi)\,\mathrm{I}(\xi) e^{-ir.\xi} \int d\xi'\, \mathrm{A}^*(\xi')\,\mathrm{R}(\xi') e^{ir.\xi'} - \int d\xi\, \mathrm{A}(\xi)\,\mathrm{R}(\xi) e^{-ir.\xi} \int d\xi'\, \mathrm{H}^*(\xi')\,\mathrm{I}(\xi') e^{ir.\xi'}$$
$$+ \int d\xi\, \mathrm{A}(\xi)\,\mathrm{I}(\xi) e^{-ir.\xi} \int d\xi'\, \mathrm{H}^*(\xi')\,\mathrm{R}(\xi') e^{ir.\xi'} - \int d\xi\, \mathrm{H}(\xi)\,\mathrm{R}(\xi) e^{-ir.\xi} \int d\xi'\, \mathrm{A}^*(\xi')\,\mathrm{I}(\xi') e^{ir.\xi'}$$

- Full details of how we derived this equation can be found in Optics Letters **29**(23): p. 2707-2709 (2004) [3]

- The small angle approximation has been used to linearise this equation and allow us to solve for the phase of the unknown wavefront.

Examples of Data



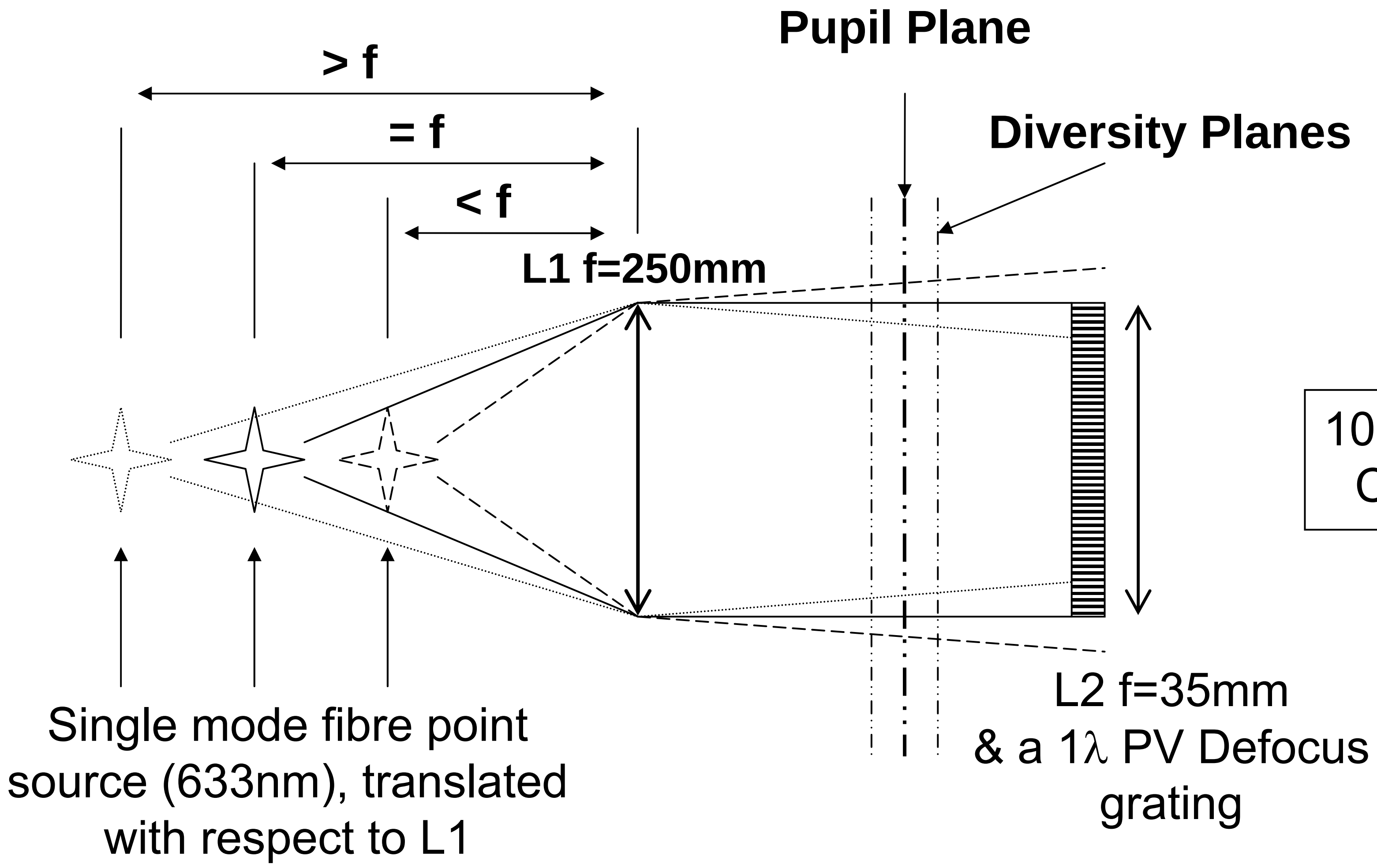
Blanchard, P.M., et al., *Phase-diversity wave-front sensing with a distorted diffraction grating.* Applied Optics, 2000. **39**(35): p. 6649-6655.[2]

- Some examples of the data seen at the focal plane.

- Easy to see the aberrations present in the data just by eye.

  - Defocus
  - Astigmatism
  - Coma
  - Trefoil
  - Spherical Aberration

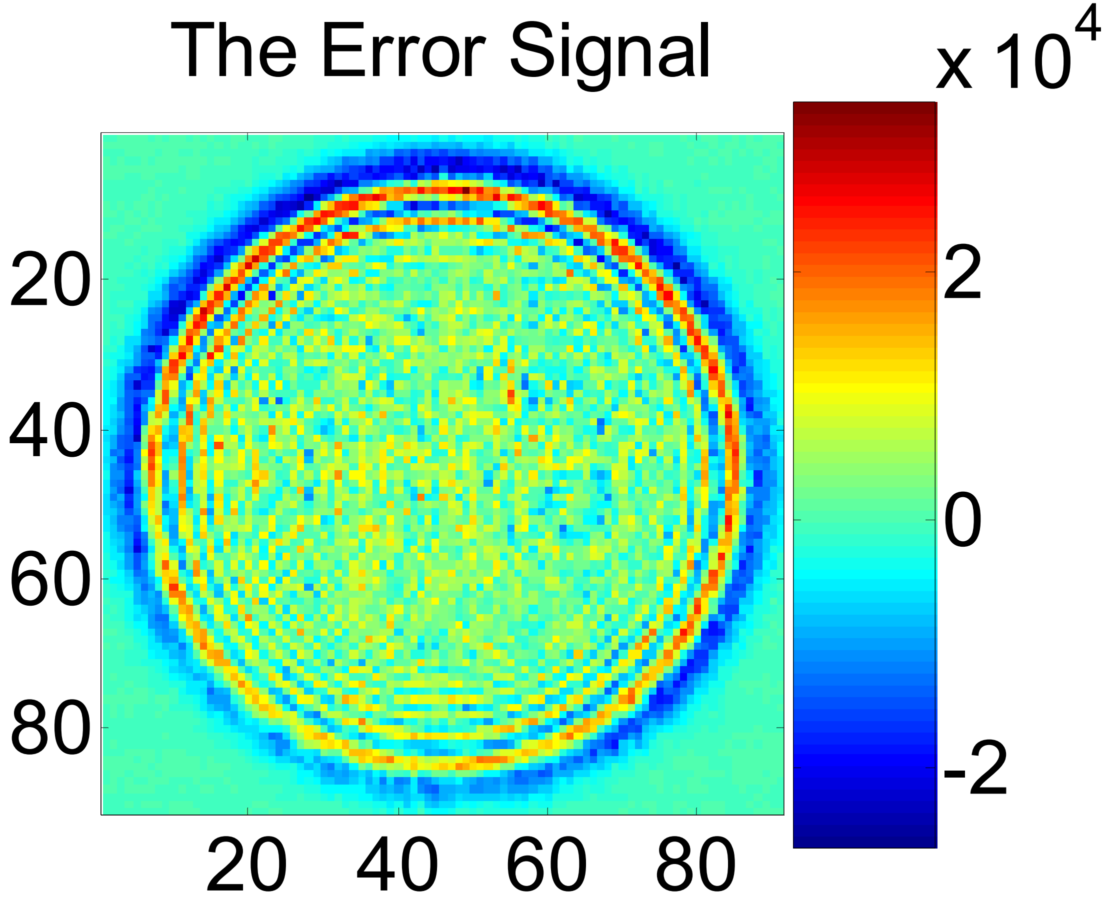
Experimental setup



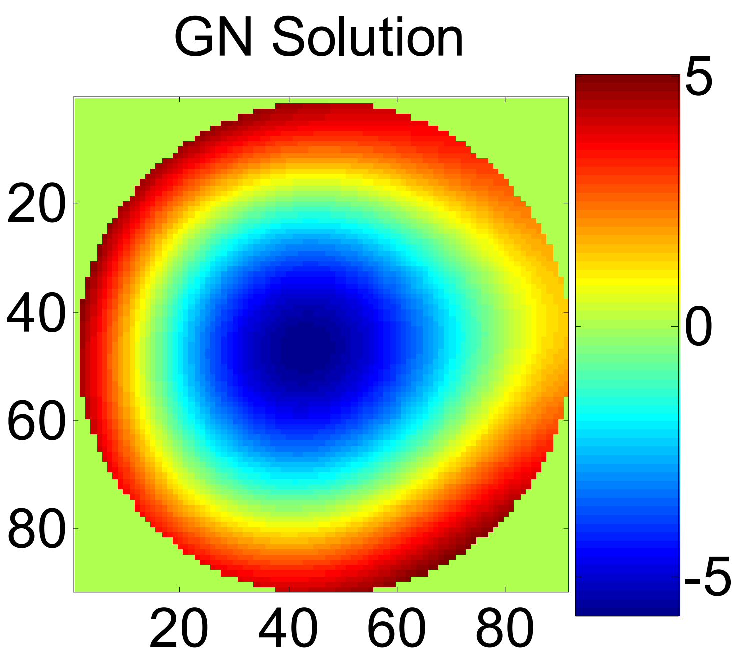
SAE vs. GN

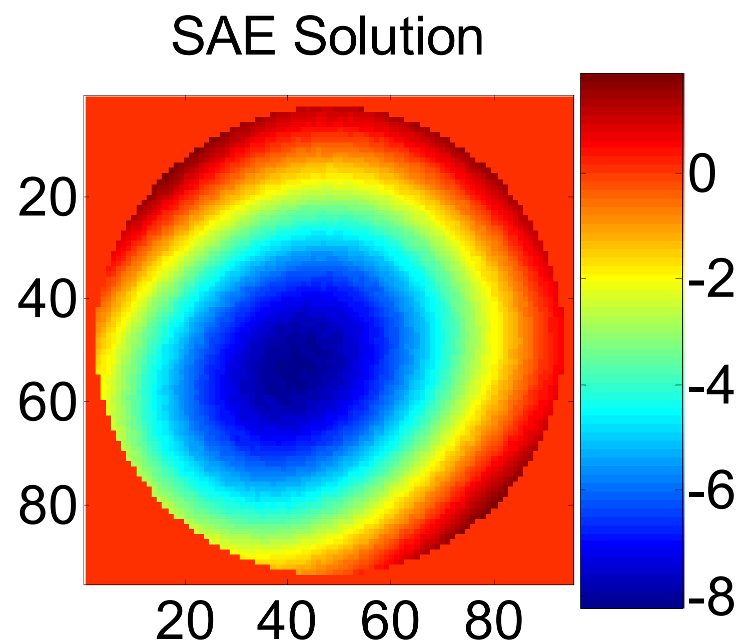
- Gureyev-Nugent Algorithm
  - ITE based phase retrieval algorithm (i.e. Defocus only).
  - Well known and fully-disclosed [4,5].
  - Reported accuracy of λ/190 [6,7].
  - Provides phase profile and decomposition into zernike polynomials.
- SAE Algorithm
  - Applies to any diversity function (including Defocus!)
  - Provides phase profile output.

Experimental Results



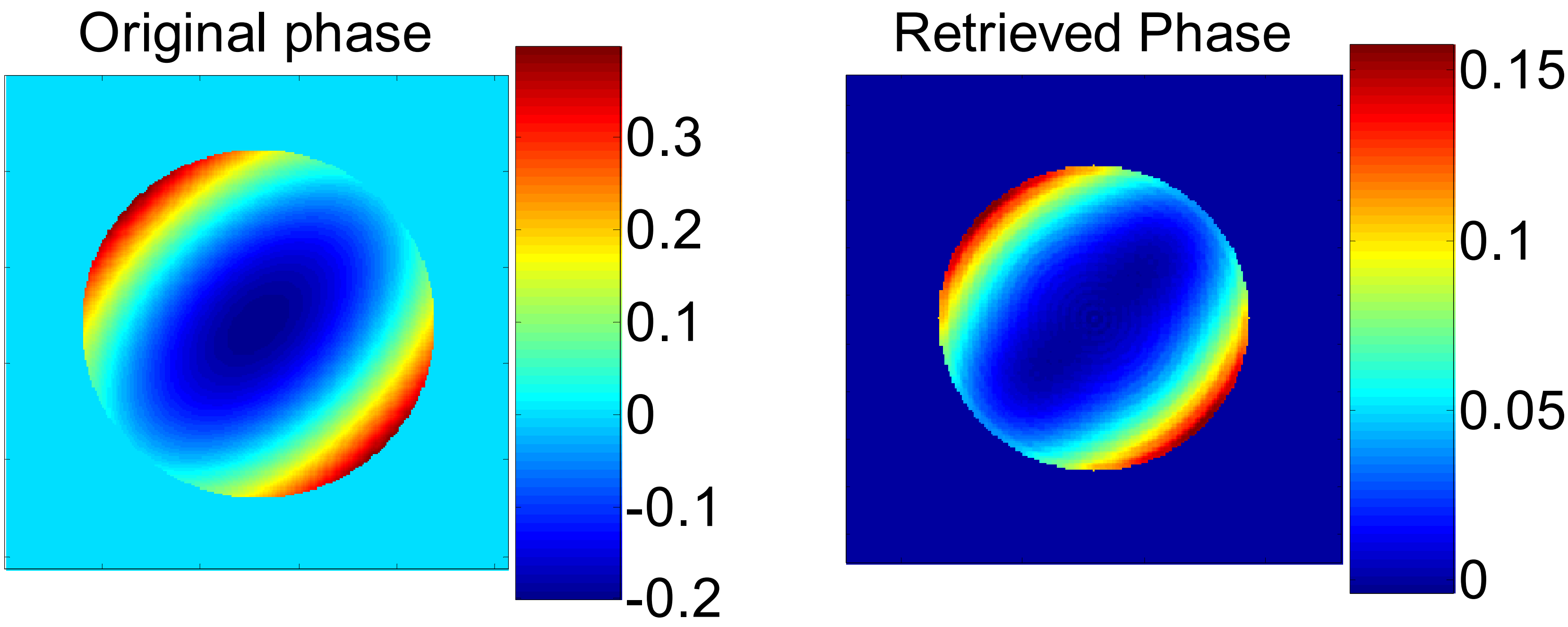
Experimental Results





- The direction of asymmetry in the SAE solution accords better with the asymmetry of the error signal.

Simulated Results



- The shape and orientation of the phase profile are correct, but there is as yet an unexplained scaling error contained in the SAE

Issues

- Boundary value problem
- Regularisation
- Scaling errors
- Orientation issues

Applications

- Metrology of discontinuous surfaces:
  - ELT mirror segment phasing.
  - Measurement of integrated circuits.
- Scintillated wavefronts
  - Atmospheric measurements.
  - Military ranging applications.
  - Astronomy applications with obscurations/secondary structures.
  - Metrology applications involving laser speckle.
- Laser machining.

Conclusions

- Preliminary results from the GPD+SAE wavefront sensor system are promising and work is ongoing to resolve the issues identified.
- The ability of this new system to cope with discontinuous and modestly scintillated wavefronts makes it suitable for a wide range of exciting applications.
- Further details of the SAE algorithm, and treatment of the problems outline today will be the subject of future presentations….

Acknowledgements

- This work has been supported through a PPARC grant under the Smart Optics Faraday Partnership, with additional support from [dstl]. HIC acknowledges support from EPSRC and the UK ATC.

OMAM Collaborators:

OMAM Funding Institutions:

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