Wavefront Sensing

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Background

- Phase diversity/curvature WFS developed using Greens functions/DOEs by Greenaway et al at Malvern (DERA)
- Further development after leaving Malvern through OMAM programme - objectives high-precision metrology applied to rough and discontinuous surfaces
- Work at Malvern patented by QinetiQ

Background

- Solutions based on ITE involve assumptions
  - Simply-connected wavefront
  - unimodular
  - continuous
  - continuous gradient

- Wish to avoid all of these assumptions….

Background

- Metrology with laser illumination
  - speckle from rough surfaces
- Segmented surfaces
  - segmented optics
  - integrated circuits
- Higher accuracy
  - sub Å for some metrology applications

Can we measure wing shape?

Diversity/Curvature

- DoE used to image Planes 1 & 2
- Solution of ITE gives wavefront

$$\frac{I_{\text{Plane 1}} - I_{\text{Plane 2}}}{z_1 - z_2} \sim \frac{\partial I}{\partial z}$$

$$\Psi(r) = -k \int_R dr' G(r, r') \frac{\partial I(r')}{\partial z}$$

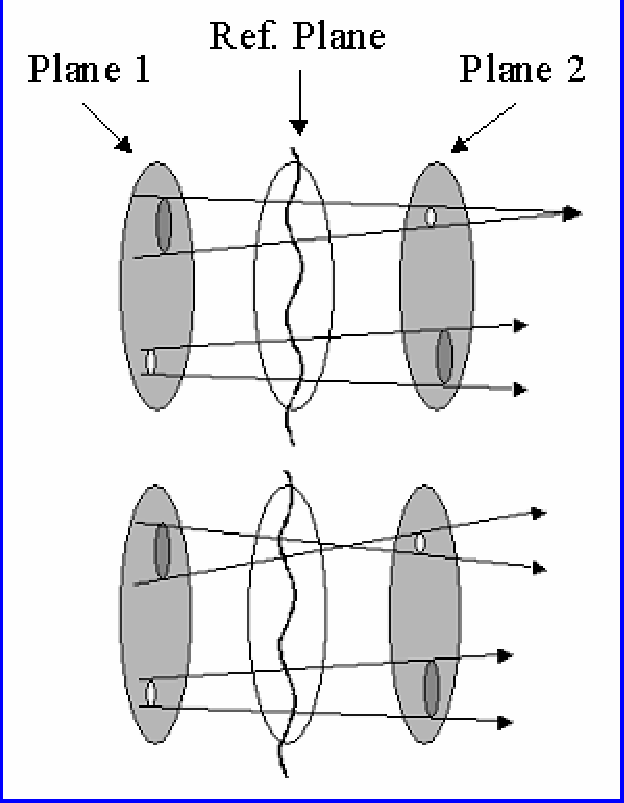
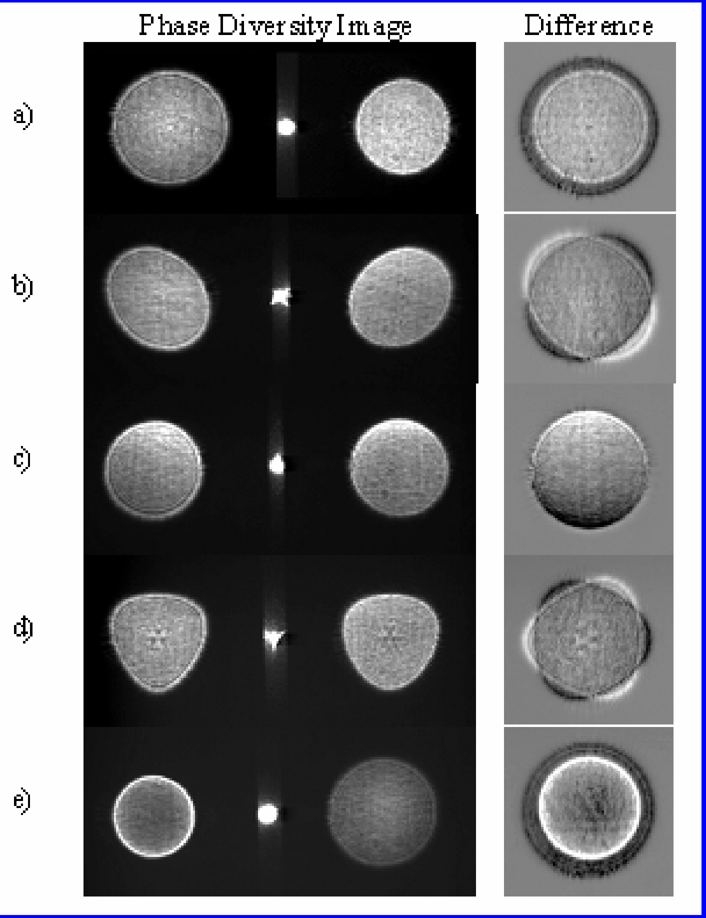


Figure 1: Two intensity planes either side of the wavefront

Diversity/curvature Data



- 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

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

GPD Theory - Definitions

- The detected phase-diversity intensity functions are:

$$j_{\pm}(r) = \left| \int d\xi.\psi(\xi).\mathrm{F}_{\pm}(\xi).e^{-i\xi r} \right|^2$$

- d(r) is the difference between the images in the ±1 diffraction order

$$\mathrm{d}(r) = 2i[\int d\xi\psi(\xi)\,\mathrm{I}(\xi)e^{-i\xi r}\int d\xi'\psi^*(\xi')\,\mathrm{R}(\xi')e^{i\xi' r}$$

$$-\int d\xi\psi(\xi)\,\mathrm{R}(\xi)e^{-i\xi r}\int d\xi'\psi^*(\xi')\,\mathrm{I}(\xi')e^{i\xi' r}]$$

Necessary & Sufficient Conditions

- *Sufficient Condition*: The difference (d(r)) between two aberrated images is null if the input wavefront has Hermitian symmetry (i.e. is purely real) and is non-null for non-plane wavefronts.

- *Necessary Conditions:*
  - The filter function must be complex.
  - Mixed symmetries (of R and I) must not be used

- Defocus kernel (curvature) satisfies these constraints

Implementation

- Defocus diversity implemented using Nugent algorithm
- New DOEs made for generalised PD
  - to be tested against interferometric soln.

➢ Current performance λ/200 with non-iterative modal solution

➢ Small-angle expansion to find non-iterative solution for generalised PD

Implementation

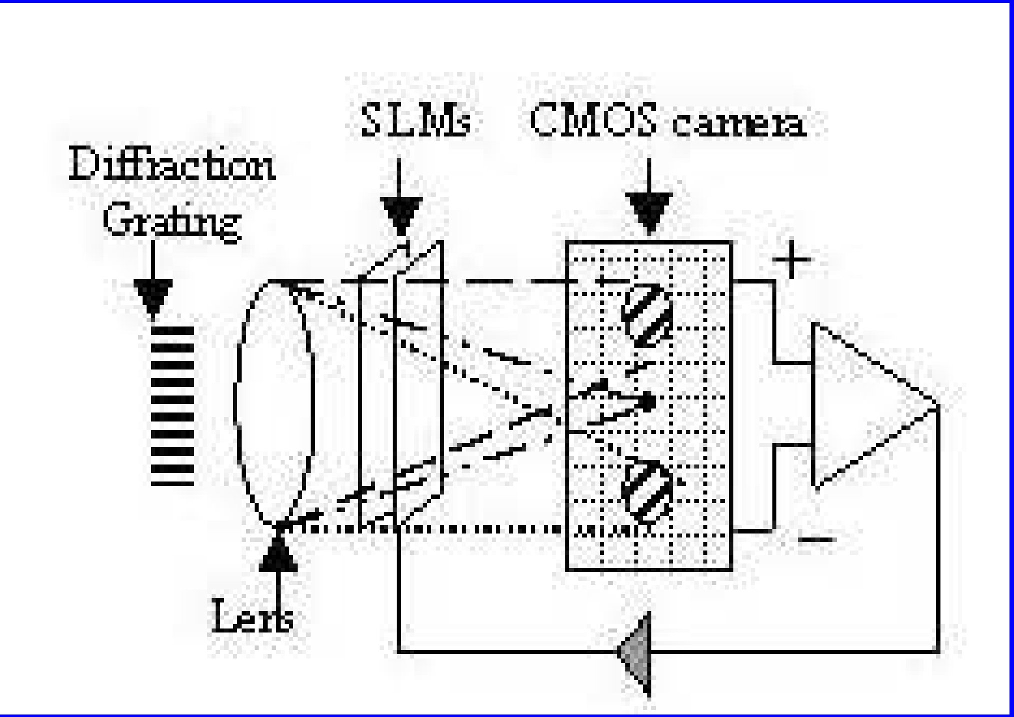


Figure 3: A suggested Compact AO System (CAOS)

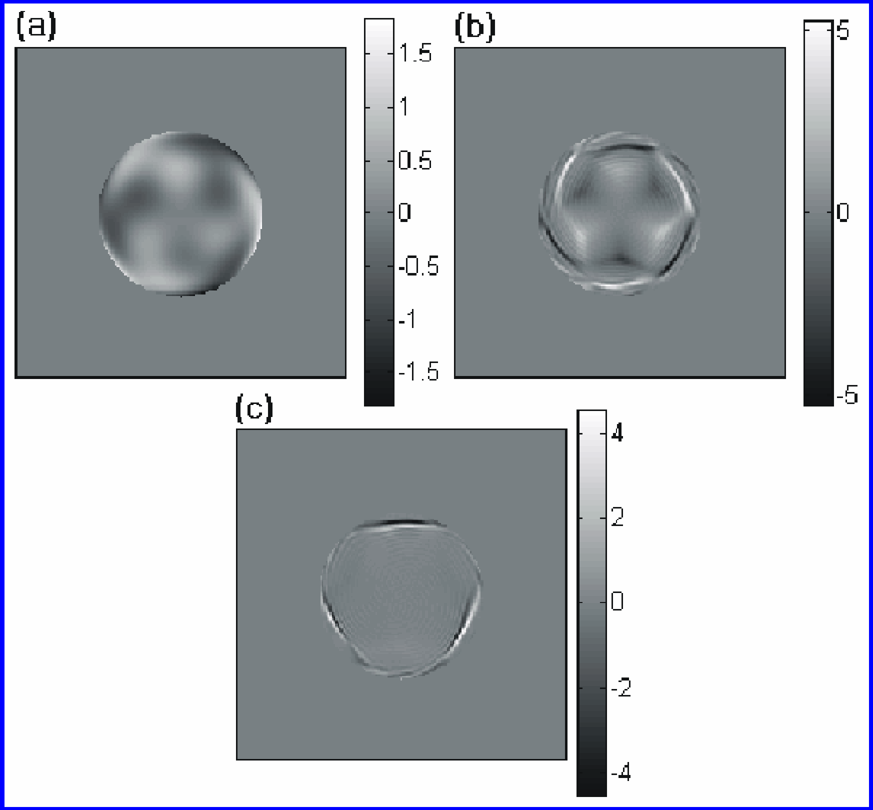
- Common path aids compact design
- SLMs provide modulation.
- DoE combines phase diverse data and corrected image.
- CMOS camera

Metrology System

- Uses DOEs to encode data as ‘snapshot’ for application in dynamic problems (e.g. fluid flow)
- Uses laser illumination - speckle
- Generalised phase diversity
- Optimise/improve WFS sensitivity
  - sub Å accuracy required for thin-film metrology
- Identical data if phase error is π ➔ no signal
  - not necessarily a problem in broad-band applications

Simulation

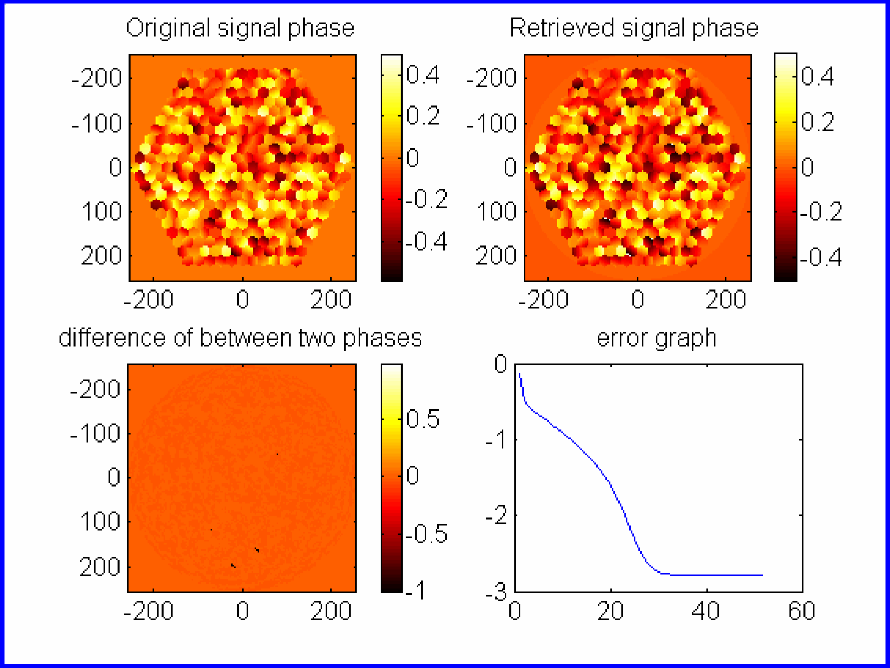
- Sensitivity improved by order of magnitude
  - spherical aberration diversity function
- Iterative reconstruction
- Nugent algorithm tried for initial approx. soln. but unsuccessful



Campbell HI et al, To appear in Optics Lett Dec 04

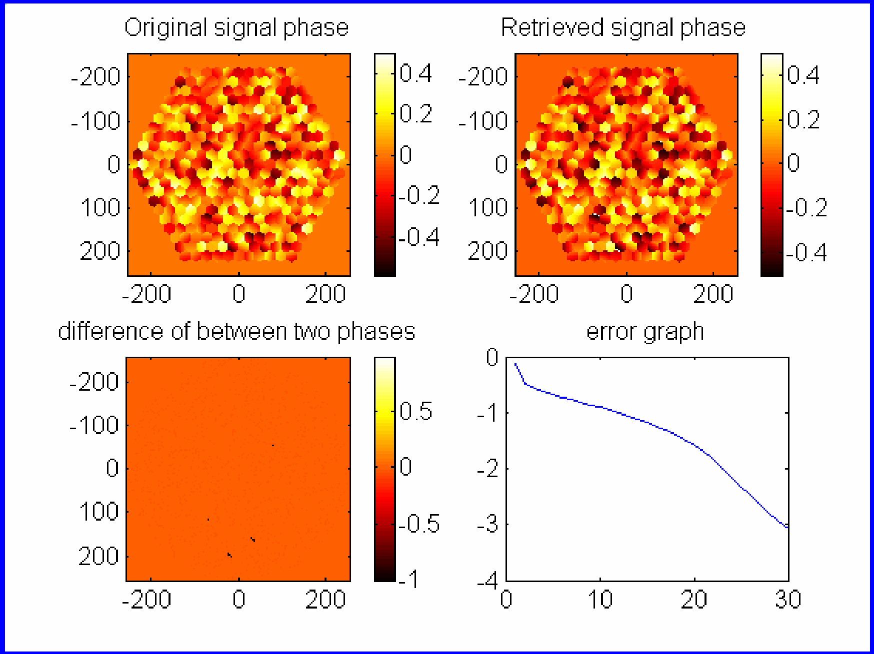
Segmented optics

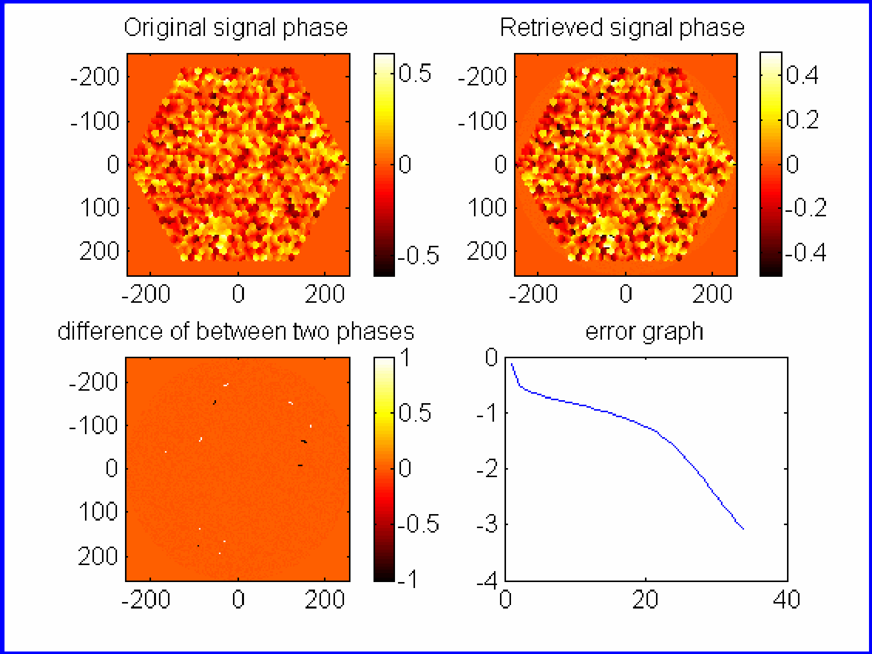
- We are presently using a Gerchberg-Saxton type iterative algorithm
- Appears to asymptote (to ~45 iterations?) for large-format segmented optics
- Analytic solution to follow (hopefully)



10 hexagon rings, 128*128 pixels
Time=4.39seconds(CPU 2.4GHz)

Simulations

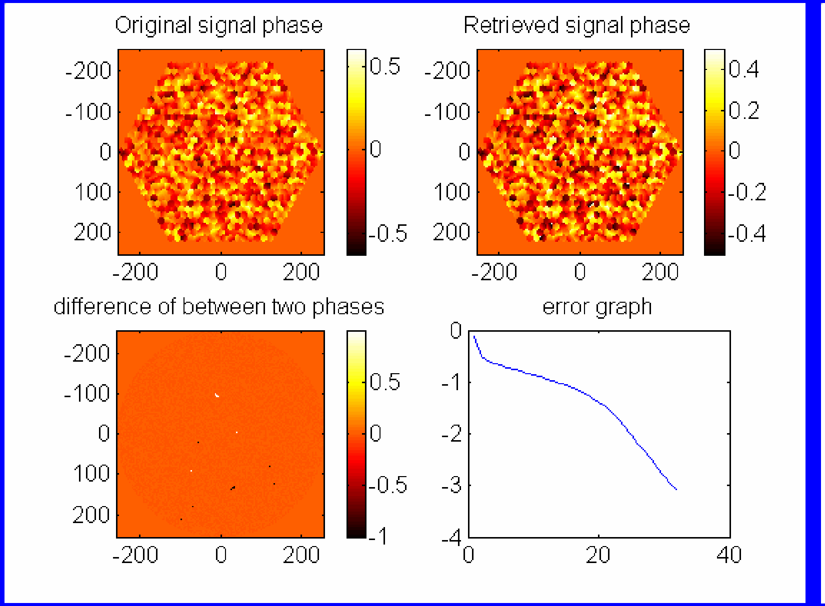


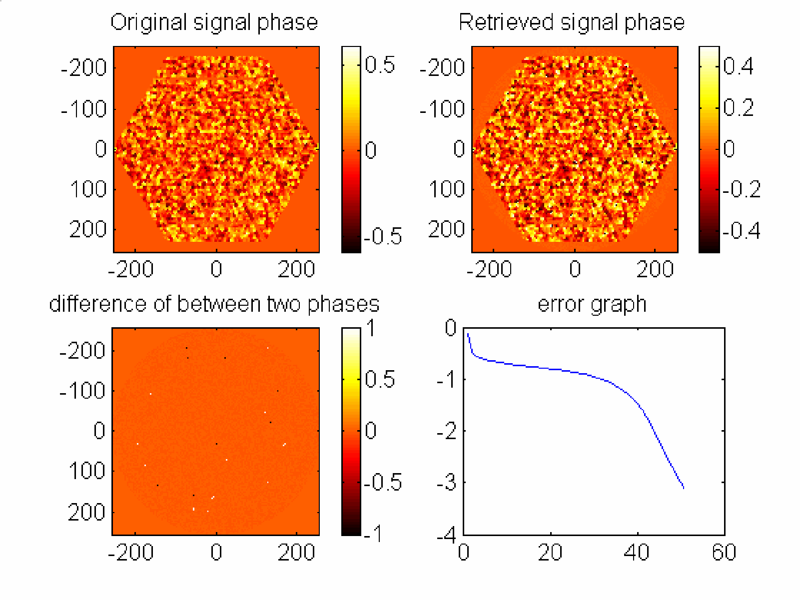


10 hexagon rings, 512*512 pixels
Time=110seconds(CPU 2.4GHz)

15 hexagon rings, 512*512 pixels
Time=141seconds(CPU 2.4GHz)

Simulations

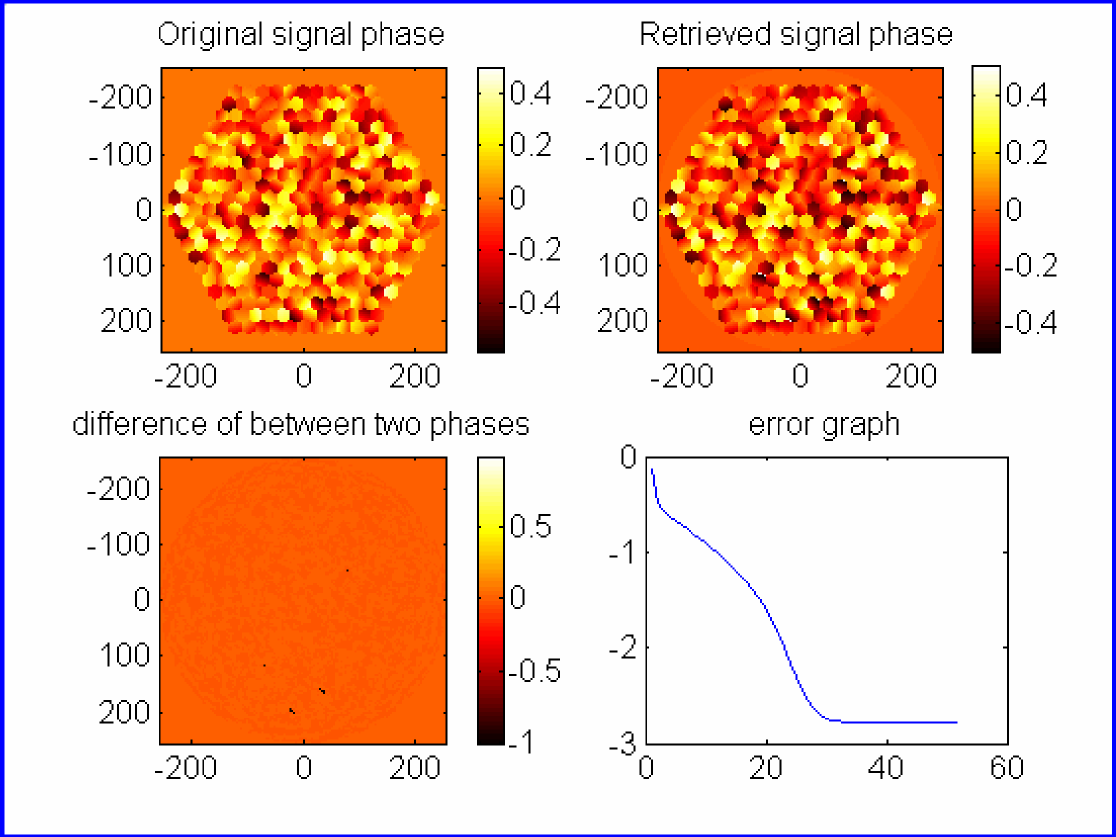




20 hexagon rings, 512*512 pixels
Time=114seconds(CPU 2.4GHz)

25 hexagon rings, 512*512 pixels
Time=192seconds(CPU 2.4GHz)

Effect of 1% noise



25 hexagon rings, 512*512 pixels

Time=186seconds(CPU 2.4GHz)