Dynamic beam shaping with programmable diffractive optics

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Outline of the talk

- Introduction
 - Holography
 - Programmable diffractive optics
- Laser scanning confocal microscopy (LSCM)
 - Aberration correction in LSCM
- Programmable reference phase stepping interferometry
- Conclusion

The principle of holography



The principle of holography



Phase only hologram



Binary phase only hologram



Liquid crystal spatial light modulator (LCSLM)





- Analog phase modulation
- Response time of the molecules :~ms
- Frame rate :60Hz
- Light efficiency :50%

Ferroelectric LC pixel



- Binary amplitude or phase (0 or π) modulation
- Response time of the molecules :~10µs
- Frame rate :1440 Hz
- Light efficiency (amplitude modulation) : 70%

Binary Hologram Design for phase and amplitude modulation



Binary phase mapping algorithm



Binary phase mapping algorithm

Complex amplitude over the pupil plane $(x,y) = e^{i\phi(x,y)}$ such that a(x,y)=1

S(mx, my) = 0 if $cos(\phi(x,y)) > 0$ $=\pi$ if $\cos(\phi(x,y)) < 0$

> Desired amplitude profile Off-axis hologram on In the pupil plane

FLCSLM

Phase delay

QuickTime[™] and a TIFF (Uncompressed) decompressor are needed to see this picture.

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Generation of arbitrary complex amplitude profile



Wide field microscope



- Collimated beam of wavelength λ is focused by L1 to a diffraction limited volume
- The illumination volume depends on $\lambda,$ focal length and diameter of the illumination lens
- A point object is imaged into a diffraction limited volume in the image space
- Resulting image has poor axial resolution

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Optical sectioning in a confocal microscope



- Confocal arrangement of focal point and pinhole blocks light from out of focus planes or points away from the optic axis
- The detector receives light mostly from the focal point
 - Image, free of out of focus blur, of a point object located at the focal point

Optical sectioning in a confocal microscope





Wide field image Confocal image (Source :www.olympusfluoview.com)

- Either the sample holding stage or the illumination spot is scanned
 - Scanning is controlled by a PC
- For each object point at the illumination spot, the detector signal is stored in the PC
- Results in an optically sectioned image (image corresponds to a sharply defined object plane, devoid of out of focus blur) of the sample
- Much better axial and marginally better lateral resolutions than a conventional (wide field) microscope



- Presence of aberrations in the illumination beam effects the performance of the confocal microscope
- Need for aberration compensation

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Modal wavefront sensor



Sensor signal= $I_2(0)$ - $I_1(0)$

- Positive and the negative bias plates adds and subtracts a certain of a zernike mode aberration
- LCSLM assembly can be used to detect and correct aberrations in terms of various zernike modes

Modal wavefront sensor (results)



Peak intensity improves by a factor of three

Aberration sensitivity and correction using a helical beam 2π

Helical phase profile across the pupil



d1

d2

 Helical type beams are highly sensitive to azimuthally dependent aberrations!

Low NA aberrated PSFs to 0.8 Strehl ratio in normal beam (normally considered well corrected)



Low NA aberration correction demonstration





- Reference mirror stepped n times with a step size $\lambda/(2n)$
- CCD records n interference patterns, where n>2
- Intensity at a CCD pixel as a function of step index is a sine wave
 - Surface profile of the test mirror manifests as phase delay
- Not effected by the inhomogenity in the beam intensity profile
- No fringe centering required
- Does not depend on the number of fringes

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Programmable reference PSI



- Accurate and repeatable phase stepping
- Reference wavefront can be programmed to match the test surface
- Accuracy in phase measurements are effected by aliasing





Fourier plane of a binarised hologram



Fourier plane of a randomly Binarised hologram





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Phase profile using 24 bit random binarization

Blue \rightarrow red \rightarrow yellow \rightarrow green \rightarrow blue Phase: $0 \rightarrow 2\pi$



Normal binarization

24 bit random binarization

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Conclusion

- Generation of arbitrary wavefront using an LCSLM
 - accurate, fast and with excellent repeatability
- LCSLM can be used both for detection and correction of optical aberrations
- Can used in a phase stepping interferometer to generate the reference beam
- Poor light efficiency
 - May effect its applicability to other areas

Thank You