Faraday Partnerships

smartmoves

The Newsletter for the Smart Optics Faraday Partnership

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MoD to speak on Defence Technology at Smart Optics Forum

Following on from the success of our space science themed forum we have organised a forum dedicated to defence applications. Keynote speaker will be Dr John Jones, MoD Director of Concepts and Technology. John will be speaking on trends in modern warfare and homeland security as they affect policy on advanced technology. Other speakers include representatives from BAE Systems, Thales and QinetiQ.

We are delighted that our forum will be taking place at the **Defence Systems and Equipment International** exhibition in London's Docklands, and registrants for the forum will gain free entry to this otherwise closed event. Further details about the forum including an up-to-date programme can be found on the Smart Optics web-site: **www.smartoptics.org**

Smart Optics at DSEi
Come and see us in conference room W27/28, 11th September 2003

Spinout Seminar

A one-day interactive seminar on entrepreneurship is being held at the UK ATC, 7th October 2003. This seminar is being organised by PPARC and Smart Optics following on from the successful KITE Club spinout seminar held earlier in the year in London (**www.pparc.ac.uk/in/lettr/spinout.asp**). The seminar is designed for PPARC-funded researchers and Smart Optics Faraday Partnership academic members who have formed, or are considering forming a spinout company. Students and postdoctoral researchers are also welcome. To register for this event please email Rachel Lloyd at PPARC: **rachel.lloyd@pparc.ac.uk** telephone 01793 442059

Smart Optics in Europe

Research into 'Smart Focal Planes' for current 8 – 10 metre telescopes and the next generation Extremely Large Telescopes is likely to be funded by the EU Framework 6 programme as part of the 'OPTICON Integrated Infrastructure Initiative'. Smart Focal Planes are optical devices to maximise use of a telescope focal plane for 3D integral field spectroscopy and multi-object spectroscopy. Examples of the technology to be developed include MOEMS, image slicers and cryogenic beam steering mechanisms. The OPTICON proposal has been favourably evaluated, and is currently in detailed contract negotiation with the European Commission, for a financial contribution of up to €19.2M. Negotiations are scheduled to be complete by mid-October, with contract completion by the end of 2003 if all goes well. Smart Optics worked with the existing Framework 5 OPTICON network of European astronomy to prepare the proposal and build the consortium. Details from Colin Cunningham at the UK ATC: **crc@roe.ac.uk**

Colin Cunningham leading the Smart Focal Planes road-mapping workshop

Smart Optics is also managing a bid for a Framework 6 'Network of Excellence' in Free-Space Optical Communications Technologies. So far 120 institutions and companies in 8 countries have expressed interest, and a partner selection exercise is underway. Details from Jon Holmes: **jon.holmes@siraeo.co.uk**

SPIE Astronomical Telescopes and Instrumentation 2004

This next SPIE conference will take place—for the first time—in Glasgow, 21 – 25 June 2004. Sub-titled "The Industrial Revolution in Astronomy", this event is to be co-chaired by Colin Cunningham, and further details can be obtained from him.

CONTENTS:

Compact Wavefront Sensing

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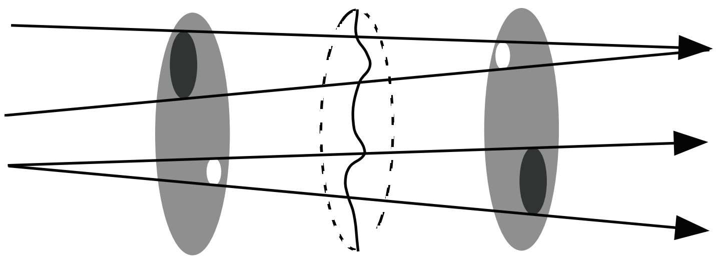
The wavefront sensor is a critical component of an adaptive optics system, but also has many applications outside of this, particularly as a metrology tool. In this article we describe how 'phase diversity' can be used for wavefront measurements and propose a compact form for the construction of a sensor employing this technique.

Phase Diversity

The idea behind the phase diversity technique is that the propagation of a wavefront can be described using the Intensity Transport Equation (ITE) [Gonsalves, 1982]. Phase diversity is usually implemented in the image plane and uses two images recorded under different defocus conditions to obtain the wavefront reconstruction. Consider figure 1:



Corrugations in the wavefront in the measurement plane (centre) will alter the local intensities of the wavefront as it propagates: a convex corrugation will cause the wavefront to converge and hence become more intense. This change in intensity is a measure of the local wavefront curvature and may be used to reconstruct the wavefront. These measurement planes are generally described as symmetrically-placed about the image plane, but can equally-well be symmetrically-placed about the system input pupil in which case the phase diversity algorithm becomes essentially the same as the wavefront curvature algorithm.

If the input wavefront is undistorted, the intensity on the two measurement planes will be identical and the difference between the images will be zero. If the input wavefront is distorted the propagation between the measurement planes results in convergence (concave wavefront) or divergence (convex wavefront) and the resulting intensity difference between the measurement planes is indicative of the location, magnitude and direction of the wavefront curvature. Hence the usefulness of this technique when considering the propagation of a laser beam through the atmosphere for object recognition or ranging.

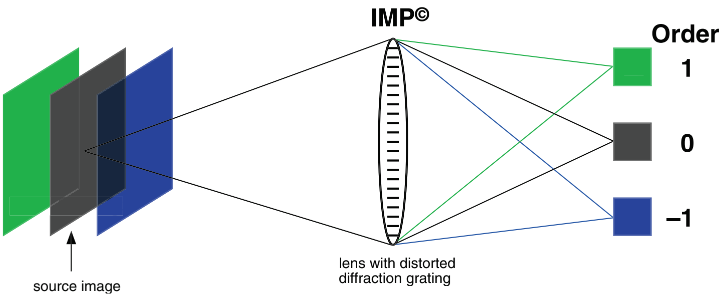
This technique can be implemented using a Green's function solution to the intensity transport equation and can give real-time wavefront reconstructions with high accuracy: the best measurements to date show an accuracy of ± 0.7nm [Djidel *et al* 2002].

For an adaptive optics (AO) system, it is not strictly necessary—and may even be detrimental—to reconstruct the input wavefront. A sufficient condition in this case is the ability to drive a wavefront modulator using a null sensor, where a control signal derived from a wavefront sensor system indicates the size, location and (preferably) the direction of the wavefront error. Thus, if the wavefront modulator is providing full correction of the input wavefront error, the control signal will be zero and the wavefront modulator will not be driven from its present position.

For applications of wavefront sensing to metrology it is usual to reconstruct the wavefront, unless the application requires no more than estimation of the deviation of the test wavefront from a pre-computed shape.

Building on the Phase Diversity Technique

The data on the two image planes is recorded using various approaches, including physical displacement of the image plane, use of a vibrating spherically-distorted mirror, beam splitters and folded optical paths, or by the use of off-axis Fresnel lenses. Each of these approaches has its merits and drawbacks, but each corresponds to the recovery of phase information from two data sets recorded under different focus conditions. As such, all of these approaches are related to the two-defocus methods applied in electron microscopy in the 1970s. A method currently employed is based on a quadratically distorted diffraction grating—essentially an off-axis Fresnel lens—to convolve the input wavefront with a defocus aberration kernel.



In figure 2 the distorted diffraction grating when combined with a lens, produces multiplane imaging of the source and records the image of the source (in the zeroth order) with the phase diverse data (in the ± 1 orders) onto the same focal plane. The distortion of the grating creates a different effective focal length in each diffraction order. Therefore, since the image distance to the CCD plane is kept constant, the object distance must vary—hence giving simultaneous multiplane imaging.

The current work on two-defocus methods has progressed a long way from the early electron microscope applications, and present techniques have demonstrated real-time data reduction with high (sub-nanometre) accuracy. However, in all cases the two data sets are recorded under conditions where the wavefront is subject to a known defocus aberration (imposed by the grating) between the two measurements. Some obvious questions that this poses are:

- what, if anything, is unique about the defocus aberration used?
- can equally satisfactory, or better, results be obtained using other aberration functions?
- if so, what generic properties should suitable aberration functions possess?
- are the restrictions on the uniformity of the input wavefront necessary?
- are there optimum aberration functions and does optimisation depend on *a priori* knowledge about the nature of the input wavefronts?
- do the optimum aberration functions depend upon whether the objective is a null sensor for use in an adaptive optics or a wavefront sensor for use in metrology or other applications?

Our work in exploring these questions amounts to a generalisation of the phase diversity approach. Such a generalisation is necessary in order to overcome the limitations of the current method, which is unable to cope with scintillated or discontinuous wavefronts. We have discovered the properties the aberration function used should have in order to provide a null sensor, which provides zero output for plane, undistorted, wavefront but which gives an error signal when the input is distorted. These properties are the 'necessary and sufficient conditions' and knowledge of these will be of use in optimising and selecting phase diversity schemes for different applications. Thus far we have placed no limiting assumptions on the form of the input wavefront other than that it be real. This means that we should already be capable of producing gratings for a wavefront sensor that will be able to cope with scintillated wavefronts. We aim to design and produce a grating based on an aberration kernel other than defocus, and implement it in a compact adaptive optics system.

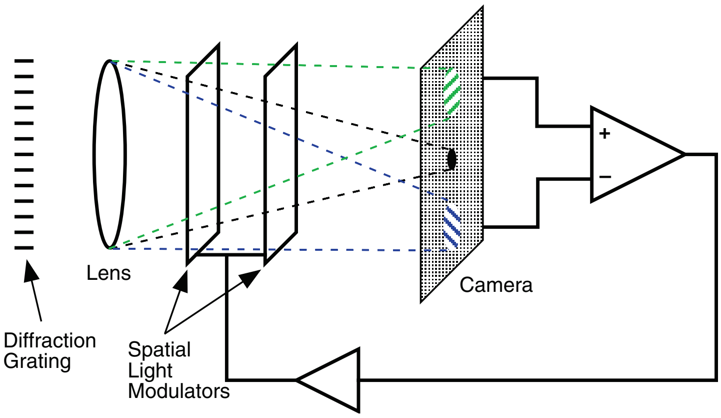


Figure 3 is a suggested design for a Compact Wavefront Sensor which works using a generalised phase diversity method. The propagation, as much as is possible, uses a common path to make this system compact. This system uses a carefully designed grating which satisfies the necessary and sufficient conditions we have established; spatial light modulators for the wavefront modulation, and an active pixel sensor camera to allow extended integration of the science image and the phase diverse data.

Conclusion

As well as using this technique as a ground-based or airborne method for target recognition and ranging, many industrial applications would benefit from a wavefront sensing method that is able to cope with scintillated and discontinuous wavefronts. In polishing applications it would be useful measure the shape of the surface being polished in real-time while it is mounted in the polishing machine. To do so would inevitably mean laser illumination of rough surfaces, which would produce laser speckle. We would also like to image integrated circuits, which are by their very nature discontinuous.

A more generalised method would be of great use in telescope design where the secondary mirror causes a large central obscuration, which gives a scintillated wavefront. Furthermore, the next generation of large telescopes will use segmented primary mirrors that are piece-wise discontinuous. This is the motivation behind our work to find a more general method of phase diverse wavefront sensing, one which does not suffer from the limitations of the existing methods and therefore can be applied to a wider range of applications.

References

Gonsalves, R A, Phase retrieval and diversity in adaptive optics, Opt. Eng. 21(1982) 829-832

Djidel, S and Greenaway A H, Nanometric wavefront sensing, In Proc 3rd Int Workshop on Adaptive Optics for Industry and Medicine, Ed Restaino S R and Teare S W, Starline Printing Inc 2002

Technology Translation

The Smart Optics Faraday Partnership has a number of 'technology translators'—business literate scientists/engineers whose tasks include supporting projects from before inception (uncovering needs) to after completion (exploitation). They do this by spending time finding out who's got what and who needs what, and then finding ways of matching the two together. Most Smart Optics supported projects comprise teams matching up a science or technology to a commercial/industrial requirement, and can include help from Smart Optics in identifying suitable funding support, be it from research council, private sector or DTI. If you have a technology of interest to the Smart Optics sector, or an industrial or commercial need that you think might be solved by Smart Optics or a supporting technology, or already have a project in mind that the Partnership might be able to help with, then please contact one of these technology translators in the first instance:

Jon Holmes—based at Sira Electro-Optics, Kent
Email: jon.holmes@siraeo.co.uk, Telephone: 020 8468 1770

Steve Welch—based at the Mullard Space Science Laboratory, London & Surrey
Email: sjw@mssl.ucl.ac.uk, Telephone: 01483 204195

Mark Bonnar—based at the UK Astronomy Technology Centre, Edinburgh
Email: mpb@roe.ac.uk, Telephone: 0131 668 8434

Current Projects

If you have an interest in any of these currently active projects, then please contact the supporting technology translator in the first instance:

Jon: ***Ophthalmoscope***—a hand held device for ophthalmology; ***Smart Marking***—use of high power lasers and SLM generated kinoforms to perform single-flash marking; ***ALFONSO***—devices for free-space optical communications.

Steve: ***Toolkit for AO***—building a set of low-cost universal AO building blocks; ***CF Mirrors***—exploring a new method for making static and deformable mirrors out of carbon-fibre; ***Adaptable Imaging Camera***—building compound lens systems using modally addressed liquid crystal devices.

Mark: ***POPS***—developing cryogenic optical pick-off arms and supporting robotics; ***Optical Metrology and Manipulation***—using wavefront sensors as a tool for extreme metrology; ***Large Optics Manufacturing Study***—preparing the UK to compete for the production of large optics; ***EZ-headset***—exploiting new displays in helmet mounted systems.

Other Open Project Threads

If you have an interest in any of the following then we would be pleased to hear from you: use of LEDs in signage or low level lighting; endoscopy or other biomedical applications; applications for a low-cost adaptive optics 'toolkit'; surveillance; industrial requirements for ultrafast (MHz) spatial light modulators. Please contact Steve in the first instance.

Diary

Details of these events are available on our website:

11^{th} September 2003 – Smart Optics for Defence Forum, co-located with DSEI exhibition, ExCel, London. Contact: Catherine.Butler@siraeo.co.uk

7^{th} October 2003 – Spinout Seminar, UK ATC. Contact: Mark Bonnar: mpb@roe.ac.uk

8-9^{th} October 2003 – Photonex 03 – Stoneleigh Business Park, Coventry

19^{th}-24^{th} October 2003 – 4^{th} International Workshop on Adaptive Optics for Industry & Medicine, Muenster, Germany

January 2004 – Smart Optics in Bio-medical Technology Forum – Cambridge. Conact: Steve Welch: sjw@mssl.ucl.ac.uk

Steve Welch speaking at the British Rocketry Oral History Programme, Charterhouse School, April 2003

New Smart Optics Faraday Partners

Applied Multilayers Ltd, advanced optical coatings; **BI Electronics Ltd**, LED lighting and signage; **Blaze Photonics Ltd**, photonic crystal optical fibre; **BPA Consulting**, technology road-mapping & consulting; **Centre for Process Systems Engineering**, advanced control algorithms; **Cranfield Unit for Precision Engineering**, ultra precision manufacture; **Datalink Electronics Ltd**, electronic Instruments; **Edinburgh Instruments Ltd**, laser, electro-optics instruments; **EM Technology Ltd**, fibre sensors, 3D imaging, tuneable filters; **Oxford Fibre Ltd**, optical fibre cleaving tools; **Parameter Optimisation Solutions Ltd**, advanced control systems; **Polatis Ltd**, micro-actuators and sensing systems; **Surrey Satellite Technology Ltd**, small satellite engineering; **UCL@Adastral**, visual Attention, Machine vision—plus the universities of **Reading**, **Paisley** and **Dundee**.

The Smart Optics Faraday Partnership is Sponsored by:

dti PPARC EPSRC