Faraday Partnerships

smartmoves
The Newsletter for the Smart Optics Faraday Partnership

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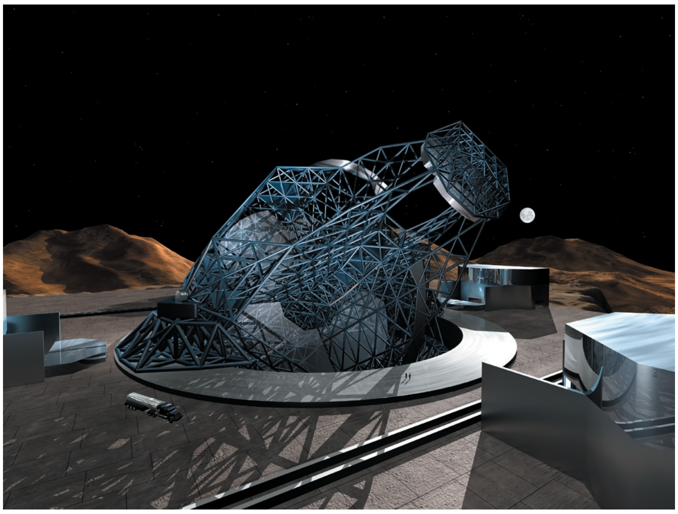
Big success for Smart Optics Partners in the Research Council's Basic Technology Programme

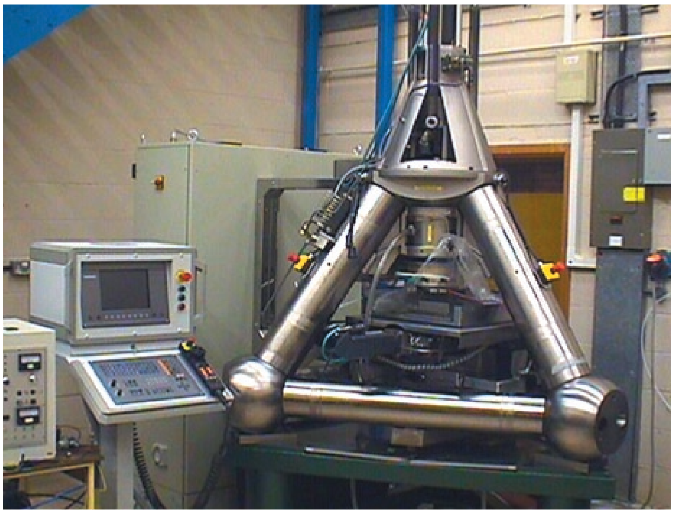
'Ultra Precision Surfaces – a New Paradigm'. A major step forward towards a renaissance of UK large optics manufacturing capability has been taken with the success of a proposal for development of processes to generate complex surfaces to an unprecedented accuracy of 1 part in 10^8. Dr David Walker of University College London's Optical Science Laboratory and Professor Paul Shore of the Cranfield University Department of Manufacturing Systems have led a team including Cranfield Precision Ltd, Zeeko Ltd, OpTIC Technium and RAPT Inc. to the award of £3.5M from the joint Research Council Basic Technology Programme, with help from the Smart Optics Faraday Partnership. Philip Parr-Burman, **ppb@roe.ac.uk** of the UK Astronomy Technology Centre will be project manager.



European Southern Observatory

ESO's Overwhelmingly Large Telescope

The project aims to develop an integrated world-class facility for processing precision surfaces for diverse applications from giant optical/IR telescopes to artificial hip joints with enhanced durability. It will provide a facility for investigations of the physical and chemical processes underlying material removal at the micron to sub-nanometre levels. The Cranfield team will develop two pioneering research facilities for producing complex form optical surfaces—a precise fixed abrasive machining system and a high-energy non-contacting system. UCL, working in collaboration with spin-out company, Zeeko, will investigate 'Precession Polishing' processes leading to a significant extension in size capability, process speed and accuracy. Eventually all of these techniques will be implemented together at the new **OpTIC Technium facility** in North Wales where collaborative research will then be directed towards optimisation of the method to process surfaces.



Tetraform polishing machine

It is one of the first two full projects involving PPARC Science to be funded by the Basic Technology Research Programme. The other is entitled M-I^3 (Multidimensional Integrated Intelligent Imaging), and will develop Active Pixel Sensors with on-chip intelligence for science applications. More information will be available at the Active Pixel Sensors Workshop run by PPARC's KITE Club on 23rd March 2004, at the Institute of Physics, London. **www.qi3.co.uk/aps**

Design LED Ltd

Illuminated signs are widely used at all scales, from the largest outside shops and petrol stations—to the smallest at point of sale. Now new LED technology is offering the potential to revolutionise commercial illuminated signage by giving the same light levels at a fraction of the running costs of conventional fluorescent tubes. Edinburgh-based technologist Dr James Gourlay approached Smart Optics to ask for help with commercialising his IP in advanced LEDs in this exciting market. We were able to identify a south-east based manufacturing partner, and assist James in setting up a new company called **Design LED** to exploit the technology. Design LED Ltd has now won a Scottish Executive 'SMART' Award to test technical feasibility, and is filing patents to protect its IP. Smart Optics will be providing additional support for the exploitation of James' technology by assisting with business planning and analysis of the market and supply chain issues in illuminated signage. **www.designledproducts.com**

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Modulated Light Cameras

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Imaging applications are currently dominated by CCD and more recently CMOS 'active pixel sensors', but these devices are not ideal for applications requiring high speed readout or very wide dynamic range. These performance limitations can be overcome by using a modulated light technique, and this article describes a low-cost way of achieving this using custom silicon chips made with standard silicon techniques.

Background

CCD and CMOS imaging devices can achieve excellent performance in terms of sensitivity and spatial bandwidth with the read noise in the best, cooled astronomical CCDs down to one electron per pixel and the highest spatial bandwidths over 5Mpixels for the best CMOS camera elements. These devices can also demonstrate impressive cost performance with the cheapest complete imaging systems with computer interfaces and optics being available for only a few pounds.

There are, however, two areas where these conventional imaging technologies do not excel—at high speed and where high dynamic range is required. While it is true that some recent CCDs can achieve frame rates of a few kHz and some CMOS cameras have demonstrated dynamic ranges of 10^5 no conventional imager is going to reach a few MHz and dynamic range always presents a problem when you have to pick a very small signal out of a large background.

These two limitations are no problem for the consumer market; the speed can easily exceed video rate and consumers don't need cameras that work faster than the eye and the dynamic range generally exceeds that of the displays (for instance TVs and monitors, although film can easily exceed these). In scientific applications it is a different story. Here there are many applications where these two limitations, speed and dynamic range, are real barriers to progress.

Modulated light cameras

This is where a new breed of image sensors steps in—the modulated light camera (MLC). These are imaging devices where each pixel is sensitive to a modulated component in the detected light rather than the DC or conventional low frequency component. Because of this frequency sensitivity a small signal can be tagged by modulating it and then the MLC can dig it out of the background. This can increase the effective dynamic range many fold.

As the modulated signal is effectively detected with a narrow bandwidth centred on the modulation frequency, out of bandwidth noise is reduced by filtering. This allows a small signal to be detected when otherwise (with a conventional imager) it would share the same frequency space as the large background, which would swamp it.

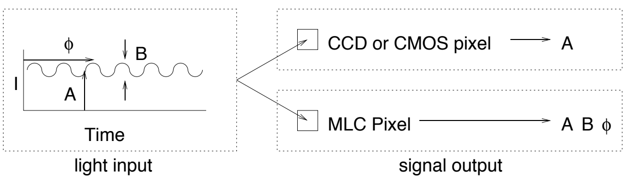


Figure 1: signals captured on conventional and MLC pixels

With a device like a modulated light camera, each pixel processes the optical signal separating the AC signal from the DC (or conventional image). The actual signal processing depends on the type of MLC but the range of on pixel processing that can be performed ranges from simple filtering to narrow band lock-in detection through to fast time-gating and sophisticated spread spectrum techniques. The range of signals that can be detected range from simple 'everything but the DC' to extremely narrow band detection of the phase and amplitude of very high modulation frequencies and complex orthogonal codes.

The modulation of the signal can be generated by the source or experimental apparatus (for instance a modulated laser), or can be modulated by the object (for instance from ultrasound passing through the beam).
The aim of the MLC is to capture more than just the DC or low frequency component of the light signal. Figure 1 shows this principle, the modulated light in this case has three properties, the DC level (A), the modulation level (B) and the phase (ø). A conventional imager only captures the DC level (A) and is insensitive to the rest whereas the MLC can capture them all. The MLC concept is not limited to imaging these three signals: it is also possible to build pixels sensitive to frequency weighted signal powers and to the frequency of the modulated signal amongst other things.

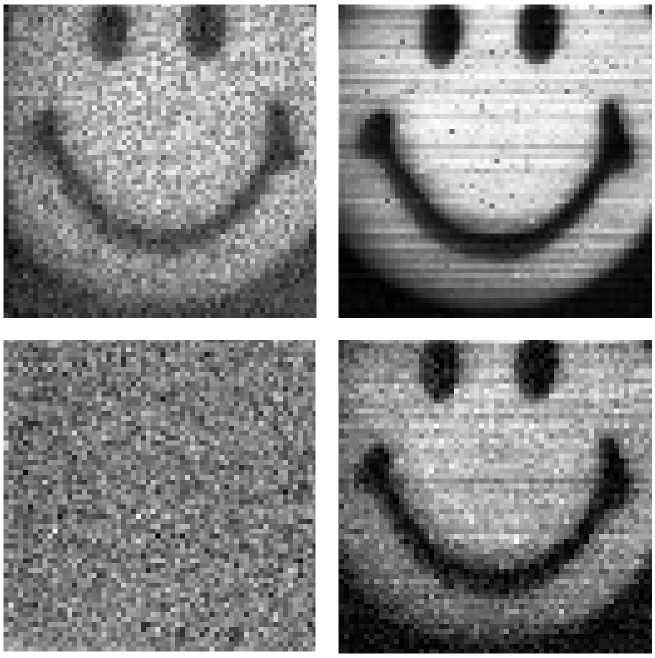


Figure 2: Images taken with the our first MLC (designed for full field surface plasmon imaging). The top row shows the DC (left) and 20kHz modulated light (right) images of an object illuminated with modulated light (3% depth). The lower row shows the DC (left) and modulated light (right) images where the camera is flooded with stray light containing no information. In this case the modulated signal depth is less than 0.1% of the background. The DC image is totally wiped out by the stray light but the 20kHz modulated image is essentially unaffected.

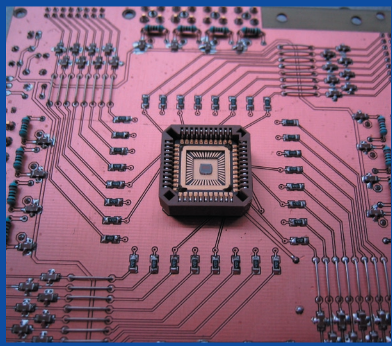
Speed

The use of local information processing is the key to MLC performance. This local processing approach makes MLCs fundamentally different from conventional cameras; an MLC performs some processing before the image is read off the chip which can result in massive signal compression whereas a conventional imager must read the raw signals off chip before any processing can be done.

With this approach it is possible to capture very high speed signals while

The Strange World of On-Chip-Electronics

Electronics on a chip can differ radically from electronics using discrete components, especially for optical chips. The reason for this is that silicon is expensive, any component which uses a lot of silicon is therefore expensive. This gives a topsy turvy world where an active circuit made of many transistors can be far cheaper than a single passive component like a capacitor or inductor. This is particularly true for optical sensor chips where the pixel size is critical because it ultimately determines how many pixels you can get for your money, for instance, the 10 pence, 10nF capacitor used in your discrete electronics circuit could end up costing many £1000s to fabricate on a custom chip whereas a high gain active RF mixer could cost a little as 10 pence. The power consumption is also critical especially in an optical chip with 1000s of active pixels, for instance in an MLC currently under design we have a budget of 35µA of current for a circuit consisting of 8 RF amplifiers, 2 active RF mixers and 4 active filters. The constraints on space, components and power make every design a challenge. Can it really be cost effective to make your own custom sensor? If you are prepared to perform the design work yourself then the economics are surprisingly attractive. The cost of fabricating an entry-level custom silicon chip is typically around £5k for the silicon through the Europractice MPW wafer service (**http://www.europractice.imec.be**). Where the design capability exists, custom sensors can be fabricated at costs that are competitive with scientific instrumentation and because the cost actually covers a small batch of chips the per chip cost of a custom sensor can fall to low £100s and actually massively undercut commercial devices if there are enough end users. At UN we try to lower the entry cost by fabricating several prototypes on the same chip prior to full chip production—we have managed to squeeze 8 separate experiments onto a single chip.



(AWFS) Close up of custom made ultrasonic wavefront sensor chip

maintaining modest (video) frame and data rates. Conventional cameras always face a bottleneck trying to push 2D data down a serial pipeline. To put it another way the MLC is able to use massive parallelism to process high speed signals and image high speed processes.

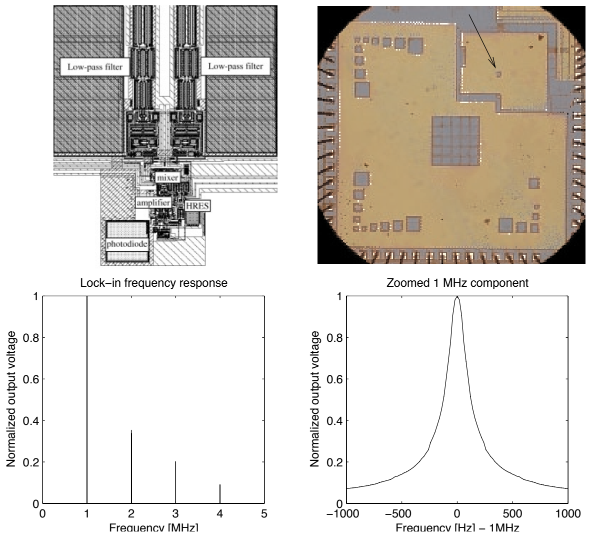


Figure 3: High frequency MLC pixel. This pixels contains active mixer elements and demodulates the optical signal with a coherent reference. The layout is top left, the microphotograph top right and the response below. This shows the pixel detecting light modulated at 1MHz with a lock in bandwidth of 150Hz—rejecting signals with frequencies 150Hz above or below 1MHz including the DC or background light. We can also detect harmonics in the signal caused by imperfect modulation. Our latest generation MLC lock-in pixel operates between 5 and 90MHz, fits (with in-phase and quadrature mixers) entirely within an 80µm^2 pixel and consumes less than 75µA of current. An array (camera) based on this pixel is planned for fabrication this year and will be used for 3D vision, heterodyne interferometry and optical ultrasound imaging.

Applications

There are many many application for MLCs, if a generic MLC camera already existed with anything like the spatial resolution of CCDs it would be a pretty safe bet that there would be several in every optics laboratory. The dominance of conventional imagers such as CCDs can tend to distort end user requirements, thus there is a tendency to want a really fast CCD instead of an imager where the pixels themselves do the work. The 'fast CCD' approach may reach a few kHz but it is never going to reach a few MHz or perform fast complex processing.

At Nottingham we are developing a number of applications for MLCs based on our newly developed sensor technologies. These applications include: 3D vision using the phase of the modulated signal to image the time of flight of light scatter from a 3D object; wide-field heterodyne interferometry with and without ultrastable signal feedback; optical wavefront detection with background light; optical ultrasonic wavefront sensing; ultrasonic imaging; ultrasound modulated optical tomography; widefield and rapid surface plasmon imaging and several biomedical applications, and we are beginning to develop technologies for GHz applications. These are just a small sample of the potential applications that could benefit from MLCs.

The IOS Group

The Applied Optics Group, in the School of Electrical and Electronic Engineering, University of Nottingham has a small subgroup dedicated to making integrated optics sensors (IOS), in particular we are focusing on MLCs as a generic technology which will enable a number of new science applications. The IOS group is relatively new and so far we have successfully fabricated 8 separate optical chips using 3 different fabrication processes. We have mainly concentrated on developing the fundamental pixel technologies required to build a wide range of MLC cameras (figure 3) but are also producing chips for wavefront sensing applications (for optics and ultrasonics) and several biomedical imaging applications.

We have recently fabricated our first full camera (see figure 2) and have plans for three new chips in 2004 including two new MLCs. These new chips will be targeted at several applications including full field surface plasmon imaging, full field (ultrastable), heterodyne interferometry, 3D vision, ultrasound detection and biomedical applications. The two different designs will be used to cover all these applications and a frequency range from ~ 10kHz – 100MHz. This will lead to much higher frequencies (10GHz) for solid state streak cameras and imaging ultrafast phenomena such as picosecond photorefractive phenomena and picosecond ultrasonics by using newly available SiGe fabrication processes.

We are currently looking for end users for these devices and for a new prototyping chip which will allow raw access to a group of pixels in a closely packed array—basically a 64^2 or 128^2 array with 64 pixels directly connected to the outside world through 64 pins at a time. This chip will allow users to develop their own pseudo imaging devices using 64 channels of their own electronics,

Continues on page 4

which can be scanned across the imaging array at high speed. We expect the photodiode frequency response to reach a 10MHz and the scan speed to reach 1MHz. This project is dependant on partner funding and we expect each system to cost in the region of £2k.

Acknowledgements

Thanks to Mark Pitter, Przemyslaw Dmochavski, Roger Light, Chayut Kongsavatsak, Steve Sharples and everyone else in the IOS group for helping prepare this document and to the University of Nottingham, EPSRC and the Paul instrument fund for funding this research.

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; ***Smart X-ray Optics***—AO for X-ray applications.

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.

Technology Translation

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:

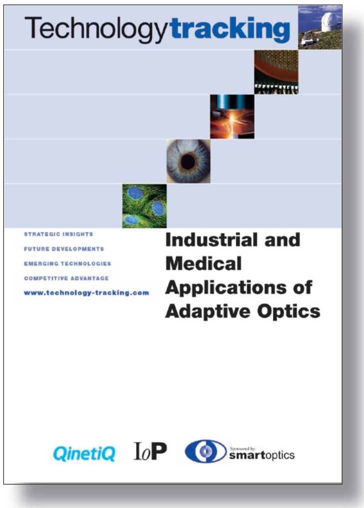
Jon Holmes—based at Sira Electro-Optics, Kent
Email: jon.holmes@siraeo.co.uk, Telephone: 020 8468 1770

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

Industrial and Medical Applications of Adaptive Optics

This excellent report written by **Professor Alan Greenaway**, Heriot-Watt University & **Dr James Burnett**, QinetiQ has just been published by the Institute of Physics. The report was part sponsored by Smart Optics and is available in hard-copy and CDROM form. We have a limited number of copies available to members at a spectacular 90% discount on the normal commercial rate. Please contact **Gillian.Maguire@sira.co.uk** for details.



Diary

Details of these events are available on our website:

23rd March 2004 - PPARC Active Pixel Sensors Workshop, London

22nd April 2004 - Smart Optics Forum, London

27th April - Games Industry—PPARC brokering meeting, London

5th May - Technology for Planetary Exploration, London

21st - 25th June 2004 - SPIE Astronomical Telescopes & Instrumentation 2004

19th - 25th July 2004 - Farnborough Air Show

New Smart Optics Faraday Partners

Applied Optics Group, Nottingham University, integrated optical techniques; **Cambridge University Engineering Department**, liquid crystals; **Centre for Vision, Speech & Signal Processing**, artificial vision systems; **City University**, sensing systems; **Design Led Products Ltd**, optics manufacturing & packaging; **Gooch and Housego Plc**, manufacturer of acousto-optic devices & precision optical components; **Intense Photonics Ltd**, device & package modelling; **Imetab Ltd**, retinal metabolic imaging research, Kingston University, medical & biological image & signal processing; **Laser Speckle Associates**, laser diodes; **Lein Applied Diagnostics**, medical applications of micro-optics technology; **Melford Resolution Ltd**, bio-science imaging; **Panchromos Ltd**, generic optical product development; **Scottish Optoelectronics Association**; **Stratophase Ltd**, microengineered crystal structures; **Technograph Microcircuits Ltd**, Opto-electronic packaging & assembly.

The Smart Optics Faraday Partnership is Sponsored by:

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