Institution: University of Southampton

Unit of Assessment: 13 Electrical and Electronic Engineering, Metallurgy and Materials.

Title of case study: 13-11 Distributed Optical Fibre Sensors within the Oil and Gas Industry

1. Summary of the impact

Research into distributed optical fibre sensing undertaken at the Optoelectronics Research Centre (ORC) at the University of Southampton has had profound economic and environmental impact within the oil and gas industries in both extraction efficiency from existing reservoirs and improved safety performance and operation of three companies: *Optasense, Stingray Geophysical* and *Schlumberger*. Each of these companies have established highly competitive positions in the worldwide optical sensor market and collectively employ more than 160 people in the south of England, in their distributed sensing programmes having benefitted from the adoption of this new technology that contributes to the management of environmental risks and hazards.

2. Underpinning research

Optical fibre sensing technology, implemented as both single point and distributed, is widely used to monitor and protect underground infrastructure including pipes and cables. It is applied to a wide range of sectors including defence, security and civil engineering, but most significantly to the oil and gas industry. Conventional electronic-based reservoir monitoring schemes have limitations: they require complex wiring, are prone to failure and only allow the integration of a limited number of sensors. Furthermore, as oil becomes harder to find, today's reservoirs are further offshore and at greater depths, leading to an increased need for more reliable ways of transmitting sensor signals over longer distances and in deeper seas.

By developing a variety of optical fibre sensors, which have allowed accurate measurement of acoustic fields, temperature and strain distributions along fibre lengths of 100km and greater, researchers at Southampton have made a significant and commercially viable contribution to the field. The International Energy Agency estimates that permanent reservoir monitoring can enhance oil recovery, contributing more than 20 million barrels per day (bpd) by 2030 (equivalent to US$2 billion). This is significant in light of estimates by the US Energy Information Administration that worldwide oil demand will increase from 83 million bpd to 118 million bpd in 2030.

The main body of work on developing acoustic sensing technology took place at the Optoelectronics Research Centre from 1999 to 2012. The research team was originally led by Professor John Dakin who joined Southampton in 1990 and became an Emeritus Professor in 2007, and more recently by Professor David Richardson, who joined Southampton in 1989 and is now Deputy Director of the ORC. Also in the team were Dr Stuart Russell, (PhD student 2000-2005, founder of spin-out company Sensoptics); Dr Trevor Newson (Lecturer from 1990-2000, Senior Lecturer from 2000 to present); Dr Ed Austin (Research Fellow 2003-2009); and Dr Shaiful Alam, (Research Fellow from 2008, now Principal Research Fellow 2013 to present).

With research grants totalling £204,800 from US company Radio Detection [3.7], who were interested in developing new techniques to locate and protect buried telecom fibres, the team developed new techniques for accurately locating disturbances (induced by strain/acoustic/RF-signals) along a length of installed fibre using various forms of fibre-based interferometry [3.1-3.3]. Their findings proved that optical fibres could be remotely located and probed with high spatial resolution and high sensitivity – a development that led directly to the formation of start-up company Sensoptics. A further project, [3.8], undertaken between 2008 and 2012, demonstrated that multiple interferometric acoustic sensors could be interrogated with high sensitivity over distances of over 500km. This was achieved by exploiting suitably adapted wavelength and time domain multiplexing in conjunction with the optical amplifier and transmission-line technology used in optical telecoms [3.4].

Work between 1994 and 2005 led to the development of new Optical Time Domain Reflectometry

(OTDR) based techniques based on Brillouin scattering [3.5]. The ORC team found that by launching a short pulse of light down the fibre and measuring the backscattered light, they could accurately determine temperature and strain distributions over distances of up to 50km achieving world-leading spatial resolution and low cross-sensitivity. Between 2003 and 2006, ORC researchers developed new techniques, based on optical amplification, to extend the reach of OTDR-based sensing from 50 to 150km [3.6]. In effect, the technique converts the entire length of fibre into a sensor, allowing continuous measurements over longer distances. This greatly extends the range of technological applications, in particular the lucrative area of pipeline monitoring [3.9, 3.10].

3. References to the research (best 3 are starred)

[3.1] J.P.W.Hayward, S.J.Russell, J.P.Dakin, "Direct monitoring of fiber extension by correlation-based coherent optical time-domain reflectometry," Optical Fiber Sensors 17 (OFS 17) conference, Bruges 23-27, 2005, P2-43.

[3.2] S.J.Russell, A.B.Lewis, R.J.Clarke, B.R.Fleury, J.P.Dakin "A novel method for location of buried optical cables where an incident EM-wave modulates the polarisation of guided light using the Faraday effect," Measurement Science and Technology, **15,** p1651, 2004.

*****[3.3] S.J.Russell, K.R.C.Brady, J.P.Dakin, "An improved 40km dual-wavelength dual-Sagnac sensor with enhanced signal processing allowing real-time location of multiple time-varying strain disturbances," Optical Fiber Sensors 14, Venice, 2000 Fr2-3.

[3.4] E.Austin, Q.Zhang, S.-U.Alam, M.Zervas, R.Slavík, P.Petropoulos, P.Nash, D.J.Richardson "500km remote interrogation of optical sensor arrays," Proc. of the SPIE 7753, 2011, 77532M-77532M-4: Eds. Bock, W.J., Albert, J., Bao.

*****[3.5] P.C.Wait, T.P.Newson ""Landau Placzek ratio applied to distributed fibre sensing,"

Optics Communications, 1996, **122,** P141-146.

*****[3.6] Alahbabi MN; Cho YT; Newson TP, "150-km-range distributed temperature sensor based on coherent detection of spontaneous Brillouin backscatter and in-line Raman amplification," Journal of the Optical Society of America B: Optical Physics, **22,** 2005, p1321.

Grants:

[3.7] Radio Detection, series of direct funded research grants (x3), PI J.P. Dakin, £204,800, 2001-2004.

[3.8] TSB, "FOSAR DEEP" project, PI D.J. Richardson, ~£320,000, 2008-2012.

[3.9] EPSRC/DTI Program, GR/L644416/01, NOMADS project, PI TP Newson, £207,629, 1997-2001.

[3.10] DTI Program (Basic Technologies for Industrial Applications), CHBL/C/019/00026, ROADS project, PI Dr TP Newson, £230,800, 2006-2010.

4. Details of the impact

The process of Research leading to Impact

Research into the use of fibre-based interferometry to locate faults and disturbances led directly to the formation of a technology start-up company, Sensoptics, in 2006. It was co-founded by Dr Stuart Russell, who developed most of the technology during his PhD. Having generated commercial interest, the company developed both the existing and new sensing approaches before successfully launching several perimeter monitoring products for improved applications in security, and subsequently diversifying into the oil and gas industry. In 2011 Sensoptics was sold to QinetiQ, an international defence and security technology company, for £2.6m [5.1], with further benefits to be paid pending commercial success. The company was later rebranded as OptaSense

[5.2]. In a 2011 press release from QinetiQ, Managing director Mike O'Connor described the technology as 'an excellent addition to QinetiQ's portfolio of sensor solutions, ... equally applicable to detecting intruders in perimeter security applications as it is to monitoring mechanical failure in critical underwater infrastructure' [5.3]. Later in 2011, OptaSense signed a £26.5m deal with Shell to monitor the hydraulic fracturing process (fracking) [5.3]. The company has grown rapidly; in 2008 it had just three employees, today it has > 120. The firm forecasts a turnover of £100m by the middle of the decade and currently exports to more than 35 countries [5.4]. This sequence of company acquisitions (Sensoptics to Qinetiq to Optasense) in which a business *has adopted a new technology* is a clear indicator of *economic impact*.

Economic and Environmental Impact

The beneficiaries of these huge commercial advantages lie across a wide range of sectors including ***civil engineering*** companies (due to improved structural monitoring); ***manufacturing companies*** (due to better process monitoring and improved safety within chemical plants); and the ***security and defence industries*** (where intrusion monitoring is paramount). However the greatest beneficiary is **the energy industry**, where greater extraction efficiency and improved monitoring and reservoir management bring vast financial and environmental benefits. It is to be noted that the worldwide optical sensors market is estimated at $2 billion [5.5, 5.6]. Further impact is evidenced through **job creation**: the three companies listed in the summary now employ over 160 people in this area of distributed optical fibre sensing.

The lead partner in the FOSAR DEEP project [3.8] – Stingray Geophysical – a leader in the use of fibre-optic sensing technology for seismic Permanent Reservoir Monitoring solutions, have reported that cost-effective permanent reservoir monitoring enables oil companies to extract more hydrocarbons from known reservoirs more quickly, more safely and more cost-effectively: a 2-3% increase in recovered hydrocarbon is worth in excess of £1 billion on a typical reservoir [5.7]. This is clear indication of the *impact on the management of natural resources (energy)* and the *introduction of new processes* for economic benefit.

In 2010, following the experimental demonstration of acoustic sensing over a distance of 500km, with the required system sensitivity, ORC researcher Dr Ed Austin was recruited by Stingray Geophysical. The development of this deep-water sensing capability was fundamental in the subsequent US$45 million sale of Stingray to the Norwegian company TGS in 2011. A press release at the time stated: 'The transaction will provide TGS with a strong position in the rapidly growing market for Permanent Reservoir Monitoring solutions.' Robert Hobbs, CEO of TGS, added: 'The age of "easy to find" oil is over, forcing oil companies to increase investment in their existing fields to extend production and increase recovery factors. The acquisition of Stingray allows TGS to access a larger portion of the reservoir optimization market.' [5.8], which is a clear indication of both *economic and environmental* impact.

Following ORC research that successfully demonstrated record long-reach, high-resolution temperature and strain measurements, Sensa Schlumberger developed a robust demonstrator suitable for field trials for both power cable monitoring with National Grid Transco and oil and gas pipe lines for BP Explorations. After further development work Sensa Schlumberger launched their Pipeline Condition Monitoring System, which was field-tested at two sites in April 2007 [5.9]. From 2008 onward the company has found applications for the system in long-distance subsea energy cable monitoring, installing six high-value projects to date. In early 2013 Schlumberger began work on a major project involving 450km of pipeline. Schlumberger Fellow Dr Arthur Hartog said: 'We think the technology can radically alter borehole seismic acquisition in particular by making it much more efficient [and] financially more attractive.' [5.10].

Finally, at the time of submission of this case study, negotiations concerning a major deployment opportunity in Brazil (estimated value US$100m and enabled by the improved business capability developed in FOSAR Deep) are currently at an advanced stage [5.7].

5. Sources to corroborate the impact

[5.1] Confirmation of Sale of Sensoptics to QinetiQ for £2.6m
http://www.qinetiq.com/news/PressReleases/Documents/Preliminary_results_announcement_for_year_ended_31_March_2011_v2.pdf

[5.2] Launch of Optasense who use Sensoptics technology on their products

http://www.qinetiq.com/news/pressreleases/Pages/qinetiq-launches-optasense.aspx

[5.3] Recognition of the role of Southampton's research on the business of Optasense
http://www.cbi.org.uk/media-centre/news-articles/2012/09/mid-cap-britain-optasense/

[5.4] Contact: CTO and Founder of Sensoptics

[5.5] http://www.bccresearch.com/report/fiber-optic-sensors-market-technology-ias002e.html

[5.6] Contact: Managing Director, Fibercore Ltd

[5.7] Contact: CTO and Founder, Stingray Geophysical, TGS Geophysical Company (UK) Limited

[5.8] Confirmation of sale of Stingray to TGS
http://www.tgs.com/Subpage.aspx?id=6278

[5.9] A comprehensive distributed pipeline condition monitoring system and its field trial
Strong, Andrew P. (Schlumberger, Southampton, United Kingdom) et al. Artem Proceedings of the Biennial International Pipeline Conference, IPC, v 1, p 711-719, 2009,

[5.10] Contact: Schlumberger Fellow, Schlumberger Fibre Optics Technology Centre