Institution: University of Leeds

Unit of Assessment: 15 – General Engineering

Title of case study: Case 3. Global sales of tomographic instruments benefiting process industries

1. Summary of the impact (indicative maximum 100 words)

Research into industrial process tomography has been performed at the University of Leeds from 1999 to the present day with much of this being in collaboration with Industrial Tomography Systems plc (ITS). This research, together with the associated intellectual property, has provided the foundation of 5 innovative new products developed and produced by ITS during the eligible period. These new products have generated sales of £5m and are in large part responsible for increases in turnover and employment of approximately 60%, and exports of 67% since 2008. These instruments are used in a significant number of new applications and are generating major benefits to end users in the oil and gas, pharmaceuticals, chemicals, consumer products, minerals and food sectors.

2. Underpinning research (indicative maximum 500 words)

Tomographic measurements enable the real time motion of liquid, solid and gas phases enclosed within a vessel to be viewed in two or three dimensions. The ability to measure flow or reaction processes is highly desirable as this can lead to improved end-product specification and/or improved processing efficiencies. The tomographic image is attained by sensing the differing electrical properties (capacitance, resistance, induction) of the material, or materials, under investigation within the volume being imaged. This presents an 'inverse' mathematical problem to then process the data from the electrode sensor to form the required image.

The research described herein took place at the University of Leeds from 1997 and continues to the present day. The principal researchers are Profs **BS Hoyle** and **M Wang**, with **Wang** joining the University of Leeds in 1999. Their research focuses on the industrial applications of tomographic techniques, such as electrical resistance tomography, electrical capacitance tomography and electrical impedance tomography, whilst working in close collaboration with Industrial Tomography Systems plc (ITS). Both **Hoyle** and **Wang** have worked extensively with Prof **RA Williams** and Dr **X Jia** during the research period.

From 1997 to 2000 **Hoyle** led an EPSRC Foresight Challenge project (GR/L22591/01, PI **Hoyle**, £510,200), where tomographic techniques were combined to form the world's first integrated multi-modal industrial process tomography [1] system, later licensed to ITS, incorporating electrical resistance, electrical capacitance and ultrasonic modes to provide enhanced data collection. This prototype was trialled by project partner Schlumberger Cambridge Research Ltd.

From 1999 to 2001 ITS provided support to **Wang** and **Jia** to further develop electrical impedance tomography. Although previously used in medical applications, electrical impedance tomography had not been fully developed and commercialised for industrial processes and offered significant advantages over X-ray techniques, providing faster measurements and a safer, less complex installation within an industrial environment. In 2000 **Wang** also received EPSRC support (GR/M94298/01, PI **Wang**, £52,750) to investigate how electrical impedance tomography could be applied to stratified flows or flows containing large bubbles or voids. This situation is common in many industrial processes where a non-conducting phase (i.e. a bubble of gas or oil) may be in contact with the electrodes of the tomographic sensor. **Wang** developed a novel conductive ring electrical impedance sensor [2] which eliminated issues relating to discrete electrodes, replacing these with a continuous sensing ring which could successfully detect up to 98% gas cut (defined as the flow rate of gas as a percentage of total flow rate).

Complex flow processes are a key application for industrial process tomography and from 2000 to 2004 **Wang** and **Williams** undertook a project with EPSRC support (GR/N28580/01, PI **Wang**,

£275,149) to develop a fast impedance tomography system. This included development of a novel scaled conjugate gradient image reconstruction algorithm [3] and an associated streamlined processing system [4] with data acquisition of 2.5 million measurements per second, offering a real-time tomographic image at approximately 500 frames per second, compared to the previous <10 frames per second. This is now able to offer new insights into flowing processes, such as vector estimation in turbulent flows. In 2003, **Wang** and **Williams** also received funding through NERC (NER/A/S/2002/00824, PI JL Best, £319,535) to investigate fluid dynamics and deposits of transitional flows and developed a 'pi'-shape sensor with associated software for analysis of two-phase flow through channels.

From 2001 to 2005 **Hoyle** led an EPSRC platform grant (GR/R22100/01, PI **Hoyle**, £218,491) with **Wang** and **Williams** as co-investigators and, from 2006 to 2010, a second EPSRC platform grant (EP/D031257/1, PI **Wang**, £266,334) was led by **Wang**, with **Hoyle** and **Williams** as co-investigators. In 2010 a further EPSRC grant (EP/H023054/1, PI **Wang**, £463,891) was awarded to **Wang** develop two- and three-phase flow metering and visualisation.

Key Researchers:
M Wang (Lecturer, 01/01/1999 - 31/07/2005, Reader, 01/08/2005 - 31/07/2007 and Professor, 01/08/2007 - present)
BS Hoyle (Senior Lecturer, 01/01/1981 - 31/07/1998, Professor, 01/08/1998 - 31/07/2012, and Research Professor, 01/08/2012 - 31/10/2013)
RA Williams (Professor, 01/01/1999 - 31/08/2011 when he left the University)
X Jia (Senior Research Fellow, 01/01/1999 - present)

3. References to the research (indicative maximum of six references)

[1]. **BS Hoyle**, **X Jia**, FJW Podd, HI Schlaberg, HS Tan, **M Wang**, RM West, **RA Williams** and TA York (2001) "Design and application of a multi-modal process tomography system", *Measurement Science and Technology*, 12(8), 1157-1165, DOI: 10.1088/0957-0233/12/8/324

[2]. **M Wang**, W Yin and N Holliday (2002) "A highly adaptive electrical impedance sensing system for flow measurement", *Measurement Science and Technology*, 13(12), 1884-1889, DOI: 10.1088/0957-0233/13/12/311

[3]. **M Wang** (2002) "Inverse solutions for electrical impedance tomography based on conjugate gradients methods", *Measurement Science and Technology*, 13(1), 101-117, DOI: 10.1088/0957-0233/13/1/314

[4]. **M Wang**, Y Ma, N Holliday, Y Dai, **RA Williams** and G Lucas (2005) "A high performance EIT system", *IEEE Sensors Journal*, 5 (2), 289-299, DOI: 10.1109/JSEN.2005.843904

References [1], [3] and [4] best represent the quality of the underpinning research in terms of originality, rigour and significance. They represent outputs that detail aspects of engineering approaches that have best led to impact within the industrial community.

4. Details of the impact (indicative maximum 750 words)

Context
The University of Leeds first licensed intellectual property (IP) arising from the referenced research to Industrial Tomography Systems (ITS) in 2004, patent [PCT/GB/01/05636] underpinning a conductive ring sensor, one of ITS's multiphase pipe sensor options [A], still sold by ITS. The Company (originally called Optomo PLC) has continued to license IP from Leeds and also drawn on the research by consulting with the University since 2001 [B].

Impact on ITS
According to the Managing Director of ITS: *"Overall, **Leeds insights have helped ITS create a world-class product portfolio**, since 2008 we have **developed and launched five innovative***

products *with the active support of research projects at Leeds:"* [A]

- **p2+**, is ITS's core electrical resistance tomography system, superseding the p2000, and was launched in 2009 with a user interface and software design based on collaborative research conducted at Leeds. [A]
- **m3c**, is ITS's core electrical capacitance tomography system launched in 2009, superseding the m3000 with an advanced user interface. [A]
- The additional functionality and user-friendly software interface of the p2+ and m3c are *"a major step forward in the industry".* [A]
- **SCG**, image reconstruction algorithm launched in 2008 based on software codes licensed from Leeds in 2008. The algorithm reconstructs raw ERT data to provide more advanced and higher resolution images. [A]
- **z8000**, a high performance two phase flow meter launched in 2008 based on software codes licensed from Leeds in the same year. This instrument's 1000 frame per second measurement capability is *"ground breaking"* [A].
- **v5r**, a new system and variant of z8000, launched in June 2013 based on electrical resistance tomography with IP licensed from Leeds in 2011. The v5r enables fast measurements of flow properties (up to 500 frames per second) and was designed for use in high conductivity environments (e.g. salt water) opening up the oil and gas sector. [A]

Sales of these products, which totalled £5m between year ending March 2008 and year ending March 2013, *"are in large part"* responsible for the **growth in ITS sales and employment of approximately 60%** over the same period. [A]

Exports have increased by 67% since January 2008 enabling ITS to sell into more than 15 countries. [A]

Impact on users

During the eligible period the five new products *"have helped open up a significant number of new applications in existing and new sectors, attracting new customers."* [A] For example:

- Biotechnology – Pfizer, Genzyme
- Chemicals – Du Pont (bulk), Johnson Matthey Catalysts (speciality)
- Environmental – Van Ord (precision land forming and dredging control)
- Fast-moving consumer goods – Unilever, P&G
- Food – Danone
- Mining – CSIRO (separation processes);
- Nuclear – National Nuclear Laboratory, Sellafield, CEA, Parsons, Energy Solutions
- Oil & gas – Statoil (oilfield flows), Petronas Technical University (UTP)
- Pharmaceuticals – GSK (product monitoring and control)

The extent to which specific users of ITS systems have benefited is regarded by the customers of ITS as strictly proprietary information. However, indicative examples of impact on users have been made available by ITS [A], for example:

- improving manufacturing efficiency and speeding up product development in pharmaceutical research and development;
- reducing waste in food manufacture by more accurately measuring mixing of products;
- improving manufacturing efficiency of auto-catalysts across 5 global manufacturing businesses;
- enhancing safety of nuclear waste processing in North America by providing experimental basis for validating process scale-up; and
- gaining valuable insight into what is happening inside vessels to ensure optimum catalyst performance

Further opportunities and new applications are continuing to open up on the global marketplace, with one example being an installation where the instrument will be used in work relating to copper mining tailings. The user stating he was impressed with the instrument's ability "*…to measure*

concentration distributions in dense mixtures of more than one phase, non-invasively, and without having to use equipment that utilises nuclear-based technology". [C]

5. Sources to corroborate the impact (indicative maximum of 10 references)

A. Letter of corroboration from Managing Director of ITS, 18th October 2013
B. 'Option Period' agreement between University of Leeds Innovations Ltd and Optomo PLC.
C. '*ITS install another tomography system in Latin America*' press release dated 15th July 2013, www.itoms.com/news/tomography-in-latin-america/

Website successfully accessed on 22nd October 2013.