Institution: University of Liverpool

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

Title of case study: Chromatic Monitoring For Industry And The Health Sector

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

The underpinning research has led to a methodology for cost-effective monitoring systems to interpret complex and emergent conditions in real-world applications. There are ten different organisations utilising the technology, benefitting the UK economy and health care provision, both nationally and internationally. These include MAST Group Ltd, Electricity North West Ltd, TMMHRC (India) and the Milestones Trust (Bristol). The impacts are (i) ***Economic:*** improving business capabilities and UK company profit margins (ii) ***Societal:*** benefiting health sector organisations in India and in the UK through improved diagnosis and care for the elderly and vulnerable; and (iii) ***Environmental:*** reducing waste and carbon footprint.

2. Underpinning research (indicative maximum 500 words)

Context: The underpinning research is a generic and novel methodology called "Chromaticity" which is for monitoring complex and emerging conditions in real world systems. Chromaticity mimics the human sensory systems such as, colour vision, hearing, taste, smell etc. It does this by extracting relevant information about complex and emerging conditions, without a surfeit of data. To give a simple example, the eye can detect very subtle differences in colour with the equivalent of only **3** spectrally overlapping detectors, whereas a man-made spectrometer may capture **1000** separate data points (non-overlapping) but fail to detect those subtle differences.

Research: The underpinning research in the Department established that using 3 spectrally overlapping detectors, efficient and cost-effective monitoring systems could be produced which outperform traditional measurement systems in monitoring complex and emergent conditions. The ground-breaking nature of the research is reflected by the large number of scientific papers (> 30 since 2006) published in high-quality scientific and engineering journals of professional Institutions. The book [3.1] is a collation of the main points reported in the >30 peer reviewed papers.

Further research has developed the chromaticity approach into different physical domains - optical, acoustic, electromagnetic, space, time, frequency etc [3.2, 3.3 and 3.4]. As a consequence impending faults in, for example, power systems and early development of medical conditions can be diagnosed before they become critical. This requires understanding the fundamental principles governing the quality and trustworthiness of information embedded in the chromatic values in these domains.

The chromaticity method was pioneered by the ***Centre for Intelligent Monitoring Systems (CIMS)*** in the Department (http://www.cims.org.uk) and resulted in 2 generic patent awards [3.5, 3.6]. The research quality is also indicated by the substantial research funding (>£3.0M) from several sources (EPSRC, EU, Industry etc). There has been substantial involvement from senior scientists internationally and prestigious awards received (Achievement Medal IEE Science, Education and Technology Division), Medal of Distinction (Bulgarian Academy of Science), North West Innovation Lecture, UK).

Key Dates: The research for the applications described above, was initiated in 1995 and evolved through more generic aspects of the methodology, to culminate in 2000 with the exploration of deployment in other areas in addition to optical fibre applications. These included: (i) space-location, time-domain and behavioural monitoring associated with assistive care for the elderly from 2000 [3.2]; (ii) acoustic monitoring of high voltage transformer switching from 2006 [3.3]; and (iii) monitoring of industrial liquids, namely high voltage insulating oils from 2009 onwards, petroleum fuels between 2006 and 2010 [3.4], biological fluids, tissue and bacteria monitoring from 2006 onwards and finally the use of intercontinental transmission of chromatic parameters (2008 – ongoing).

Key researchers: Professor J. Spencer, Head, Electrical Engineering, Electronics and Computer Science; Emeritus Professor G. R. Jones, Honorary Senior Research Fellow; Dr. A. G. Deakin, Senior Research Assistant; Dr. D. H. Smith, Senior Research Assistant; Dr. K. Wong, KTP Associate (MAST), Mr A Pate, KTP Associate (Fairbanks), Dr. S Xu (now at Guangzhou University).

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

3.1. Jones, G. R., Deakin, A. G., Spencer, J. W. (Editors) (2008). "Chromatic Monitoring of Complex Conditions". Book published by CRC Press, Florida, USA for Institute of Physics, UK. ISBN 13:978-1-58488-988-5; Particularly: CH 1 – 3 "Basic Principles" p. 3-47; CH 5 "Chromatic Monitoring of Industrial Liquids" p.93-112 ; CH 8 "Chromatic Monitoring of Biological Tissues and Fluids" p.159-189; CH 10 "Chromaticity of Acoustical and Vibration Signals" p.213-238; CH 11 "Chromatic Monitoring of Activity and Behaviour" p.239-265

3.2. Xu, S., Jones, G. R. (2008) "Non Intrusive Activity Assessment of a Vulnerable Individual for Real Living Environments". *Meas. Sci. Technol.* **19** 045208 doi:10.1088/0957-0233/19/4/045208

3.3. Oraby, O. A., Spencer, J. W., Jones, G. R. (2009) "Monitoring changes in the speckle field from an optical fibre exposed to low frequency acoustical vibrations". Journal of Modern Optics, v 56, n 1, p 73-84, January 2009. doi:10.1080/09500340802450573

3.4. Jones, G. R., Deakin, A. G., Brookes, R. J., Spencer, J. W. (2009) "A Portable Liquor Monitoring System Using a PC-Based Chromatic Technique". Meas. Sci. Technol. 20. 075305 doi:10.1088/0957-0233/20/7/075305;

3.5. Jones, G. R., Spencer, J. W., Dodds, P. S. (Priority date 31/03/ 2004) "Non orthogonal Monitoring of Complex Systems" GB patent 0407267.4

3.6. Jones, G. R., Spencer, J.W., Deakin, A. G., Zhang, J. (Priority date 31/03/ 2004) "Non-orthogonal Signal Monitoring" GB Patent 0407272.4

Key research grants and awards:
There has been substantial funding from several sources: (i) European Technology Transfer Grants [ERDF] (2000-2006, £2.5M). (ii) EPSRC (2006 – 2010, £511k) Supergen V – Amperes "A sustainable energy infrastructure". (iii) Deputy Prime Minister's Office (Assistive Care Grant (2005 – 2008, £197k)), (iv) Two KTP grants (a) Bacterial monitoring (2007-2010, £181k) and (b) Forecourt Petroleum monitoring (2006 – 2008, £137k); (v) HV Transformer Monitoring Industry funded (2009-2013, £300k); (vi) EPSRC – Knowledge Exploitation Laboratory – funding to embed chromaticity in MHA (2009 – 2010, £167k).

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

The underpinning research within CIMS has allowed the development of a chromatic sensing methodology allowing cost-effective monitoring systems. The CIMS system has been used to interpret complex and emergent conditions in several real world applications. This has led to ***significant economic, societal*** and ***environmental impact*** with ***national*** and large ***international reach***. There are currently ten different organisations utilising the technology, benefitting the UK economy and health care provision both nationally and internationally. The impact includes, but is not limited to, the four specific examples given below:

1. Time domain chromaticity with optical fibre, acoustic sensing developed at Liverpool [3.1, 3.3], has been retrofitted onto High Voltage transformers in sub stations operated by Electricity North West Ltd (ENWL) and Western Power (WP). CIMS engaged Manchester-based manufacturer (MHA Lighting [5.3]) to build monitoring units. 35 units have now been produced and installed in ENWL substations in the Midlands and the North West, allowing early detection of incipient

switching faults. This has resulted in an important contribution to the provision of reliable electric power supplies nationally. The resulting impact is therefore upon both industry and society in general via reduction of the risk of widespread power disruption. Furthermore: ***"Without these monitoring units and the chromatic processing methodology, ENWL would not achieve some of its regulatory aims and objectives in terms of the future energy infrastructure"*** [5.1].

2. Space domain chromaticity with 2D digital camera imaging developed at CIMS has been used to monitor growth of bacterial colonies in urine [3.1]. This led to the development of the MAST "UriPlus" urine monitor which was then evaluated by 3 independent hospitals and one medical laboratory [5.4]. Following successful field trials the UriPlus instrument was launched in 2011. To date, there have been 25 units manufactured. Furthermore there are 5-year consumables contracts in place with end-users (from 2012 and ongoing). This represents a revenue income stream of £2.5 million over the 5 year period in question [5.2]. In addition to economic benefits, the MAST UriPlus monitor provides improved diagnosis of health threatening conditions for medical patients, through the urine screening product because of its higher accuracy and ease of use: ***"…MAST UriPlus was found to be a much improved instrument over the Matascan Elite in ease of use, speed of use, user friendly software and improved accuracy"*** [5.4]

Further research and development regarding space domain chromaticity has also been applied for the detection of antibiotic effectiveness to treat bacterial infections. This has been transferred from CIMS to MAST via a KTP award. The researcher trained during in the project, as the KTP associate, is now employed by MAST. Chromaticity is embedded in the new MAST instrument, funded through this KTP award. The resulting performance of the instrument is superior to previous versions [5.3] and ***"…reduces waste and carbon foot print"*** [5.8].

3. Optical domain chromaticity [3.1] for skin tissue monitoring is being used internationally. An inexpensive mobile phone camera-based chromatic system is being used at the Thengana Medical Mission Hospital & Research Centre (TMMHRC) and 3 hospitals in South India for the live monitoring of jaundice in newly born infants (from 2010***). "The scale of the sociological importance is reflected in the fact that 9 million babies are born in India each year and neonatal hyperbilirubinemia occurs in more than 60% of late preterm and term newborns***" [5.5]. The CIMS system allows poorer sections of the population, in remote areas, to have access to improved diagnosis with consequent improvement in healthcare.

4. Space- and time-domain chromaticity with optical and infra-red sensing [3.1] has been employed for the non-intrusive ***assistive care of the elderly*** in the UK. An assistive care system covering three wings of a Care Home for the elderly, (Milestones Trust Bristol) has been in operation for 10 years with continuous evaluation (2003-ongoing). A further 8 room system was successfully tested at The Oakes, Merton Care Home, London which won a Government e-Innovation Award.

Summary of end-user beneficiaries**:**
(i) Economic: Electric Power Distribution Companies (ENWL WP etc) including their industrial customers. Instrument manufacturers (e.g. MAST Group Ltd, MHA Lighting Ltd) [5.1,5.2, 5.3]
(ii) Societal: Healthcare sectors (NHS) with an International reach to the impact via TMMHRC (India) [5.5]. Improvement of patient care for elderly residents in care homes (Milestones Trust) [5.6].
(iii) Environmental: The UriPlus instrument contributed to the NHS LEAN target performance indicators for the MAST group [5.8]

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

Economic and manufacturing impact:

5.1. The Research and Development Manager at Electricity North West can corroborate impact of monitoring systems on transformer infrastructure to improve reliability and "***achieve regulatory aims and objectives in terms of the future energy infrastructure***

5.2. The Managing Director at MAST GROUP Ltd. can corroborate revenue and industrial development impact.

5.3. The Managing Director of MHA Lighting can corroborate industrial collaboration, training and instrument development.

Societal and healthcare impact:
5.4. MAST UriPlus System: Product details on MAST website. Original reports are available (on request) from MAST Group Ltd.- *a) Cork University Hospital* (14/05/12)(Verification report LF-C-PAT-METHSVR) *b) Leeds General Infirmary* (04/02/11) Leeds Urine Screening Results. *c) Southampton Regional Laboratory* (10/08/10) d) GSTS, St.Thomas Hospital, London, evaluation poster, IBMS (25/09/11);

5.5. The Managing Director, Thengana Medical Mission Hospital & Research Centre (TMMHRC) can corroborate successful use of Bilirubin Mobile Phone Monitor. Additional reports are also available from TMMHRC. b) MM Hospital, CHC Hospital, Deeksha Multi-speciality Hospital, India; b) Dr. A. Kamle (independent assessor's report).

5.6. The Facilities Co-ordinator at the Milestones Trust Care Home can corroborate use of the Space- and time-domain chromaticity system and impacts on care of the elderly.

Environmental impact:
5.8. The Managing Director at MAST group can also corroborate how the work of the group have improved LEAN target performance indicators and therefore environmental impacts.