Institution: University of Central Lancashire

Unit of Assessment: 15 General Engineering

Title of case study: Synergistic impacts from cross-sectoral research and development of signal and image processing technology for aerospace non-destructive evaluation and medical non-invasive diagnosis

1. Summary of the impact

A unique aspect of the signal and image processing research at the University of Central Lancashire (UCLan) lies in exploitation of the synergies between non-destructive evaluation (NDE) of aerostructures in the aerospace manufacturing sector and non-invasive diagnosis (NID) of patients in the medical sector. For the former, through collaborative research with world leading aerospace companies, data processing technologies used in medical NID have been exploited to ensure structural safety of aircraft at reduced time and cost. For the latter, through collaborative research with the UCLan led Europe-wide network which includes top medical research centres and hospitals, sensing technologies used in aerospace NDE have been exploited to create new measurement modalities for quantitative medical diagnosis of major diseases. Furthermore, arising out the cross-sectoral and interdisciplinary research the Tele-immersive Digital Manufacturing facility (TiM) emerges as our vision for the factory of the future which has attracted investments from the world leading digital technology providers and made impacts on one of the most important manufacturing regions in the world.

2. Underpinning research

Aerospace NDE: The impacts on this area stem from research led by Shark and Matuszewski. Since 1997 they have been in receipt of the following funding: EPSRC (GR/L34464 and GR/R08377), EU framework programmes (INDUCE, INCA, INDeT and TATEM), [Material redacted], in collaboration with 90 organisations in 16 countries including top aerospace companies such as Airbus, Alenia, BAE, Dassault, EADS and GE with a total award >£1.7M (total project value >£53M). The research has led to a rich body of signal and image processing technologies which have significantly enhanced the defect detection capability of NDE, not only for inspection of advanced aerostructures (such as large cellular structures manufactured by concurrent superplastic forming and diffusion bonding (SPF/DB) of titanium), but also for emerging inspection modalities (such as laser ultrasound).

In signal processing, techniques have been developed for detection and restoration of short transient and extremely weak signals severely corrupted by high scatter noise in order to achieve high sensitivity for porosity and bonding assessment, which include fuzzy wavelet threshold, genetic algorithm optimised filtering, higher order statistics, joint signal-image processing, and matched wavelets. (An example of underpinning research in one of these areas is described in reference 1.)

In image processing, techniques used in medical NID have been extended to achieve rapid aerostructure sentencing based on ultrasonic, radiographic, shearographic and thermal images, which include sub-pixel high-precision image mosaic construction, robust image registration based on CAD models, multi-modal fusion based on feature distributions, and reconstruction of individual CAD models from NDE for manufactured parts.

The success of the underpinning research with BAE is also evidenced by two Chairman's Bronze Awards for innovation received, one for Data Integration and Processing for NDE and the other one for NDE Method for SPF/DB Structures.

Medical NID: Our work on three new measurement modalities for medical NID was inspired by the sensing technologies used in NDE. Led by Matuszewski, dynamic 3D optical scaning has been pioneered for facial dysfunction assessment in collaboration Royal Preston Hospital[2], and image

processing software has been developed for monitoring of cancer radiation therapy delivery in collaboration with LJMU and Christie Hospital[3,4]. The work has been funded by EPSRC since 2007 through a series of grants (EP/D077540/1, EP/D078415/1, EP/D077702/1, EP/F013698/1, EP/H024913/1) with a total award around £1.3M, and led to

- the Engineering and Computational Sciences for Oncology Network (ECSON) led by UCLan in collaboration with Christie Hospital and LJMU (plus 24 organisations from 6 European countries including AGH University in Poland, French National Institute for Research in Computer Science and Control (INRIA) and National Centre for Scientific Research (CNRS) in France, Italian National Research Council (CRN), Otto von Guericke University in Magdeburg, Germany and associated research hospitals),
- a set of software tools for improved radiation therapy planning and delivery[3,4],
- one of the most comprehensive dynamic 3D databases of human facial expressions[2],
- a novel statistical surface deformation model for facial articulations,
- an initial clinical study supported by NIHR with a quantitative measure developed based on facial asymmetry for facial dysfunction assessment of stroke patients[2], and
- a recent award by EU FP7-ICT-2013-10 (Grant 611516) (SEMEOTICONS project) to develop an innovative face-based health monitoring mirror.

Led by Shark, acoustic emission (AE) that is widely used for structural integrity assessment was investigated in collaboration with Blackpool Hospital as a new tool for condition monitoring of human joints. Funded by Arthritis Research Campaign (Grant Ref.17542), the work has led to

- a prototype system for dynamic knee joint assessment with a standardised measurement protocol[5],
- a breakthrough discovery of AE based biomarker linked to knee ageing and degeneration through a small-scale clinical trial[6], and
- a recent award by MRC (MR/K008269/1) to undertake a major follow-up clinical trial.

3. References to the research

1* Shark L-K and Yu C: “Design of matched wavelets based on generalized Mexican-hat function”, Signal Processing, Vol.86, No.7, pp1451-1469, 2006.

2 Matuszewski BJ, Quan W, Shark L-K, McLoughlin AS, Lightbody CE, Emsley HCA and Watkins CL: “Hi4D-ADSIP 3-D dynamic facial articulation database”, Image and Vision Computing, Vol.30(10), pp713-727, 2012.

3 Marchant TE, Price GJ, Matuszewski BJ and Moore CJ: “Reduction of motion artefacts in on-board cone beam CT by warping of projection images”, British Journal of Radiology, doi:10.1259/bjr/90983944, Vol.84., pp251-264, 2011.

4* Marchant TE, Skalski A, Matuszewski BJ, “Automatic tracking of implanted fiducial markers in cone beam CT projection images” Medical Physics 39(3), pp. 1322-1334, March 2012.

5 Mascaro B, Prior J, Shark L-K, Selfe J, Cole P and Goodacre J: “Exploratory study of a non-invasive method based on acoustic emission for assessing the dynamic integrity of knee joints”, Elsevier Medical Engineering & Physics, Vol.31(8), pp1013-1022, 2009.

6* Shark L-K, Chen H and Goodacre J: “Knee acoustic emission: a potential biomarker for quantitative assessment of joint ageing and degeneration”, Elsevier Medical Engineering & Physics, Vol.33, No.5, pp534–545, 2011.

*Best indicating quality of underpinning research

4. Details of the impact

Aerospace NDE: With signal and image processing technology development driven by aerospace companies, there is a direct path to impact on their aircraft safety with increased defect detectability, assessment reliability and manufacturing competitiveness with reduced inspection time and costs. A good example is production NDE at BAE, who have funded a series of projects to industrialise the signal and image processing techniques developed from research to radiographic and ultrasonic inspection of large and complex shaped aerostructures produced using advanced manufacturing processes[1]. In particular, our work has

- influenced the development of real-time digital radiographic and multi-axis ultrasonic NDT

facilities currently being used at its aircraft production site,
- significantly reduced the data acquisition and analysis time for aerostructures manufactured using SPF/DB of titanium, and
- enabled inspection of new aerostructures which would be impractical with conventional NDT methods.

Furthermore, the signal and image processing technologies developed for aerospace NDE have been extended to submarine NDE[2]. [Material redacted].

Medical NID: By developing image processing software for planning and monitoring of cancer radiation therapy, by pioneering dynamic 3D facial scan and joint AE as new medical diagnosis tools, the research in medical NID contributes directly to improving the efficacy of assessing and monitoring the condition and treatment of cancer and stroke which are two leading causes of death, and arthritis which is a major cause of disability.

The significance of the research output for cancer treatment stems for the plethora of algorithms and software tools developed for image registration, segmentation, tracking, deformation modelling and detection for multi-scale data, starting from cell level, through tissue level to organ level. These software tools are used widely by the ECSON members for various medical applications[3]. A subset of our image segmentation algorithms is publically available and is one of the most downloaded Matlab mathematical packages[4]. The success of these tools has formed the foundation of a new grand research challenge to understand and model the effects of ionising radiation on the biomechanical properties of cells.

The significance of dynamic 3D facial scan lies in its specificity and sensitivity to detect small facial changes over time, which could be too subtle for clinicians to notice. With the method being simple, fast and non-invasive, it opens up potential clinical applications in neurological conditions associated with facial dysfunction. The initial clinical study was supported by NIHR to measure facial symmetry. Further clinical study would be required, but improved prediction of prognosis in conditions such as Bell's palsy would be one example of conceivable clinical application[5]. It has also led to an FP7 project on a face-based health monitoring mirror (SEMEOTICONS).

In joint AE, the significance lies in the development of a novel movement-based joint assessment using the AE waveform profiles related to dynamic interaction of internal anatomical components instead of static imaging based on X-rays, MRI, and ultrasound. In addition to being shortlisted in 2011 as the Times Higher Education Research Project of the Year Award (with Lancaster University for far-reaching impact and catching the public imagination), there was a wide media coverage of the Joint Acoustic Analysis System (JAAS) including BBC news[6] and a successful clinical trial establishing an AE based biomarker for identification of knee joints in different age bands and conditions (healthy and osteoarthritic). JAAS is now commercially available from Physical Acoustics[7] and is to be used in a large-scale multicentre longitudinal study funded by the MRC (MR/K008269/1). The work was in collaboration with a [Material redacted], and builds the foundation for a new discipline of musculoskeletal AE.

Tele-immersive Digital Manufacturing facility (TiM): This was developed at our Burnley campus as our vision for the factory of the future that is affordable and internet-accessible. It emerged as an interaction between of the technology push to extend signal and image processing expertise (developed for aerospace NDE and medical NID) to big data and the application pull towards ICT-enabled manufacturing by the world leading manufacturing companies (from the aerospace, automotive, energy, food, nuclear and submarine sectors in the region). The development has brought in major investment from the top ICT companies such as CISCO to provide the state-of-the-art networking infrastructure[8] and has attracted joint research on future manufacturing with the centres of manufacturing excellence such as Sheffield AMRC and Warwick WMG (as evidenced by a 5-year >£2M project funded by EPSRC, EP/K019368/1). The facility offers BAE Systems and its suppliers an off-site demonstrator plant for the trial run of ICT technologies to evaluate their impact on production, provides a platform for cross-fertilisation of ideas on the factory of the future[1] and accelerates ICT technology take-up by regional SMEs for manufacturing (with 57 SMEs assisted

through ERDF funded projects of PARADIGM and DigitME). It has also helped to create a new image of manufacturing in young people through outreach activities and in society through high profile visits (including senior government ministers such as the Secretary of State for BIS) and HM The Queen with HRH Duke of Edinburgh in The Queen's diamond jubilee tour. All of these have contributed to the award to Burnley as the Most Enterprising Area in the UK by BIS in 2013 "for its on-going commitment to support small and medium sized businesses and for successfully reframing perceptions of Burnley"[9].

5. Sources to corroborate the impact

1 CONTACT 1: [Material redacted] BAE Systems Military Air & Information
2 CONTACT 2: [Material redacted] BAE Systems Maritime – Submarine
3 http://www.ecson.org
4 http://www.mathworks.co.uk/matlabcentral/fileexchange/24998-2d3d-image-segmentation-toolbox
5 CONTACT 3: [Material redacted] Royal Preston Hospital
6 http://www.bbc.co.uk/news/health-10630883
7 CONTACT 4: [Material redacted] Mistras Group
8 http://www.lancashiretelegraph.co.uk/news/burnley/9386232.Burnley_s_UCLan_campus
9 CONTACT 5: [Material redacted] East Lancashire Chamber of Commerce