Institution: Nottingham Trent University

Unit of Assessment: D34 Art and Design: History, Practice and Theory

Title of case study: Advanced Textiles

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

Research in electronic textiles, described in five granted worldwide patents, is having impacts in the health, sports, defence and fashion sectors. The central impact claimed comprises bringing second generation electronic textiles into manufacture through knitted garments for older people for vital sign monitoring that have been commercialised by a spin-out company, SmartLife Technology Ltd, and the development of a conductive suit for the Ministry of Defence. Work in the unit has also underpinned the development of electrically heated gloves by EXO2 Ltd and a new test for a hip protector system based on an advanced 3D spacer structure by Baltex Ltd. Baltex Ltd and EXO2 Ltd also plan to use the technology to develop additional products.

2. Underpinning research (indicative maximum 500 words)

Research in advanced textiles dates back to1980 (e.g. Brackenbury 1992) based on established expertise in textile fibre materials, digital textile manufacturing processes and garment construction. In 2008 the School of Art and Design recognised the importance of designing electronically active advanced textiles for wearable systems, which resulted in the development of textile stretch sensors by bringing together expertise in knitting, weaving, embroidery and garment construction (**section 3, i**).

Research in this area was enhanced under the leadership of Professor Dias who joined NTU in April 2010 to lead the Advanced Textiles Research Group (ATRG). Integrated wearable computing requires a new generation of transducers, for which, the background research involves developing and integrating three basic technologies: novel fabrication of transducers, low power microelectronic and adaptive signal processing techniques. Since 2010, Dias has led research to understand the electrical properties of knitted structures when they undergo static and dynamic deformations, generating knowledge that can be used to develop fibre based transducers for wearable computing and in the next generation of SMART clothing to measure internal environmental parameters such as body vital signs (ECG, breathing rate, breathing patterns, skin temperature, perspiration, bodily electrical activity, body motion and gesturing).

The demand for this form of transducers arose from the limitations associated with rigid sensors ‘bolted on’ to garments to achieve wearable computing. This first generation of smart clothing attaches rigid sensors to the garment using traditional textile processes such as sewing and gluing. Their shortcomings led to the development of fabric transducers that incorporate electro-conductive fibres/yarns in the non-conductive base structure during the fabric manufacturing process, which will make second generation smart clothing possible. Applications for these devices in smart clothing have been developed in partnership with Loughborough University (Communications Group), University of Sheffield (Communications & Radar Group) and University of Salford (Centre for Health, Sport and Rehabilitation Sciences) (**Section 3, iii, iv**).

The unit’s research identified major challenges in second generation technologies for smart clothing caused by the inherent hysteresis of textile structures which limits their application to only relative measurements. Truly smart textile structures and clothing must be able to carry out absolute measurements, analyse data and respond accordingly, so we decided in 2010 to research the possibility of embedding semiconductor micro devices into fibres and yarns, using a conformable polymer resin to bind the chip with the fibres of the yarn.

The objective is to position encapsulated chips along the length of the yarn at predetermined intervals without compromising fabric manufacture. The encapsulation hermitically seals the chip thus protecting it from all forms of stresses (mechanical, thermal, chemical, etc.). This will produce intelligent electronic yarn capable of physical sensing, signal processing, transmitting and receiving, which will form the basic building blocks of truly flexible, drape-able and washable textile computers in the near future, creating the “third generation” wearable computing.

Brackenbury, T. (1992) Knitted Clothing Technology, London: BSP Professional

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

i. Kettley, S., Downes, T., Glazzard, M., and Harrigan, K. (2011) Fit for Purpose? Pattern Cutting and Seams in Wearables Development. Digital Creativity. vol 21. No 4. p247-256. http://dx.doi.org/10.1080/14626268.2010.548870

ii. Dias, T., Preece, S., Kenney, L., Major, J., Lay, E. and Fernandes, B., Automatic identification of gait events using an instrumented sock, Journal of NeuroEngineering and Rehabilitation; vol. 8, 2011, pp. 1-10; http://www.jneuroengrehab.com/content/8/1/32.

iii. Tennant, A., Hurley, W. and Dias, T. (2012), Experimental knitted, textile frequency selective surfaces, IET Electron. Lett. 48, 1386

iv. Acti, T., Zhang, S., Chauraya, A., Whittow, W., Seager, R., Dias, T. and Vardaxoglou, Y, High performance flexible fabric electronics for megahertz frequency communication, LAPC 2011, Loughborough, IEEE Conference Publications 2011, pp. 1-4. DOI:10.1109/LAPC.2011.6114088

v. Delkumburewatte, G. B., and Dias, T. (2011) Wearable cooling system to manage heat in protective clothing, The Journal of the Textile Institute, vol. 1. pp.1-7 http://dx.doi.org/10.1080/00405000.2011.587647

vi. Dias, T., and Monaragala, R., Development and Analysis of Novel Electroluminescent Yarns and Fabrics For Localized Automotive Interior Illumination, Textile Research Journal, vol. 82, 2012, pp. 1164 – 1176. DOI: 10.1177/0040517511420763

The outputs 1-6 above have been independently reviewed in preparation for REF2014 at above 2*.

Evidence of quality of research:

- Prof Tilak Dias (PI, NTU); Prof Yiannis Vardaxoglou (PI at Loughborough University); "High performance flexible, fabric electronics for MegaHertz frequency communication"; collaborative research project with the School of Electronic, Electrical and Systems Engineering at Loughborough University; Project duration: 01st October 2010 – 30th September 2013 (36 months) Funded by EPSRC/IeMRC; Grant value £201,962 (NTU) and £202,056 (LU)
- Professor Glen McHale (Principal Investigator); Professor Tilak Dias (Co-Investigator); "Smart Materials – Designing the functionality"; Project duration: 02nd January 2011 – 30th June 2012 (18 months); Funded by EPSRC feasibility study programme; Grant value £199,000
- Professor Tilak Dias "The development of clothing with fully embedded electronics for military applications"; Project duration: 01st February 2012 – 31st January 2016 (48 months); Funded by the National PhD Programme, DSTL; Grant value £154k,
- Professor Tilak Dias (Principal Investigator at NTU); Dr Alan Tennant (Principal Investigator at University of Sheffield); "Knitted Electromagnetic Functional Textiles for LO Applications"; Collaborative research project with the Department of Electrical & Electronic Engineering at Sheffield University; Project duration: 01st February 2012 - 31st July 2012 (6 months); Funded by DSTL; Grant value £30,378 (NTU) and £15,334 (UoS);
- Professor Tilak Dias (Principal Investigator at NTU); Dr Alan Tennant (Principal Investigator at University of Sheffield); "Manufacture of conducting textile electromagnetic structures using flat-bed knitting and laser ablation techniques"; Collaborative research project with the Department of Electrical & Electronic Engineering at Sheffield University; Project duration: 01st September 2012 – 28th February 2013 (6 months); Funded by DSTL; Grant value £31,998 (NTU) and £26,300 (UoS);
- Professor Tilak Dias; "Seamless knitted prosthetic sleeves for the management of perspiration"; Project duration: 24th September 2012 – 23rd March 2013 (7 months); Funded by DSTL; Grant value £66,404

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

In the past decade a great deal of interest has arisen in the field of electronically active smart textiles. A market growth in this sector is estimated as 28.3% annually and in 2009 put the world market value at €469million [Smart Fabrics, http://www.smartfabricsconference.com]. As such there has been intense worldwide research interest in electronically active textiles in the last few decades, but only a very few research groups specialise in specific technical aspects of these structures. The broad scope of our research group and its focus on fusing scientific, engineering and design disciplines to create novel and innovative electronically active smart textiles makes our research unique internationally. Our resultant smart yarn technology has a profound effect on the production and use of electronic textiles in clothing applications by providing robust functionality that is resistant to wear, washing and drying and can be produced at lower costs than the electronic textiles available today where functionality is often added at the garment stage. Our technology has a wide range of potential applications, in health, sports, defence and fashion sectors. The work has resulted in commercialised products and processes, some of which have been patented since 2010 demonstrating impact arising since Dias joined NTU as follows:

Health Monitoring Garments

Basic research on knitted transducers fed into the formation of a spin-out company SmartLife Technology Ltd, applying the knowledge described in patents (**section 5, i, ii, iv and vi/**), granted while Dias has been employed at NTU. SmartLife exploits the technology in a range of sectors for remote condition monitoring of heart rate, breathing patterns and skin temperature. The devices developed from the research can transmit the data wirelessly in real-time for analysis. http://www.smartlifetech.com/ As the technical director of SmartLife put it of the contribution Dias' work has made to the company: '…his original research is the centre of our work'. The company spent £250,000 on R&D in 2012 and projected a spend of £100,000 in 2013 and 2014 to generate innovations from Dias' inventions.

Defence sector- Electrically conducting suit (MoD)

The Ministry of Defence conducted experimental trials on a seamless knitted garment designed and made from electrically conducting yarns by the Unit, applying the knowledge in patent (**section 5, iv**). The beneficiary is the MoD research establishment at Porton Down. The details and the outcome of the trials cannot be disclosed (see section 5 for corroborating evidence).

Sports Sector- Heated Glove Liner

A knitted glove liner with five heating elements and conductive pathways was designed for a UK SME, EXO2 Ltd. The technology to manufacture the knitted glove liner on a commercial scale was also developed, and a UK knitwear manufacturer 'Skinwear Ltd', who is capable of producing the glove liner for EXO2 was identified, and the technology developed was transferred to Skinwear. Currently the EXO2 product is on the market as a ski and motorcycle glove. There has been recent adoption of the technology by the Indian military. Sales since 2010 have led EXO2 to acknowledge the considerable potential of the technology. Half have been sold to a significant UK outdoor clothing brand which has its own retailers (Rohan Design). In addition, further products are being developed with EXO2, the Clinical Sciences Centre of the University Hospital Aintree and the Raynaud's & Scleroderma Association for the management of Raynaud's phenomenon. The technology is also being developed by EXO2 in conjunction with another company for use in automotive textiles and personal apparel. Beneficiaries are EXO2, Rohan design, Skinwear, their investors and purchasers of the products.

Health sector- 3D Spacer fabrics for use as hip protectors

Baltex Ltd approached us as they were developing 3D spacer fabrics for use in hip protectors for the elderly. We subsequently developed a test method for screening the hip protectors. The test method has now been adopted by Baltex. Beneficiaries are Baltex, their investors and their customers.

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

The results of the knowledge created has been protected in the following IP:

i. 'Knitted transducer devices'; IN239317 (granted on 16.05.2010), IL171734 (granted on 01.09.2010), AU2004237945 (granted on 06.05.2010), HK1096832 (granted on 07.01.2011), CN1882280 (granted on 26.05.2010), US2009018428 (pending), CA2525525 (pending), JP2006528897 (pending)

ii. 'Contact sensors'; GB2444203 (granted on 06.04.2011), NZ566921 (granted on 08.08.2011), AU2006296395 (pending), CA2623171 (pending), EP1976429 (pending), US2009203984 (pending)

iii. 'Knitting techniques'; GB2444443 (granted on 23.02.2011), US7779656 (granted on 24.08.2010)

iv. 'Linear Electronic Transducer'; EP2245223 (granted on 16.11.2011), US2011030127 (pending), JP2011510700 (pending), CN102084048 (pending);

v. 'Operative devices installed in yarns'; EP1882059 (granted on 07.07.2010), US2009139198 (pending)

vi. 'Pressure Garment'; EP1756343 (granted on 11.04.2012);

Beneficiary Testimonials:

Fibre Embedded Electronics

Technical director of SmartLife.

Electrically conducting suit (MoD)

Please contact Technical Lead, Defence Science and Technology Laboratory for further details.

Heated Glove Liner

Interview with CEO EXO2

EXO2 web page: http://www.EXO2.co.uk/thermoknittrade-ezp-11.html