Institution: Ulster - REF UoA 13: Electrical and Electronic Engineering, Metallurgy and Materials

Title of case study: Integrated Healthcare Sensors underpin Global Connected Health

1. Summary of the impact

NIBEC connected health related research over the past 20 years has led to three high value spin-out companies. Their success is based on exploitation of over 35 NIBEC patents in medical sensors and electro-stimulation devices. Together these companies are currently valued at almost £100m, employ over 150 skilled people and have engineered medical innovations that have had global beneficial impact on health costs and patients' lives over these past four years. Our research is closely linked with international partners, commercial and clinical, has impacted local government policy through our leadership of the European Connected Health Alliance and has resulted in the £5m industry-focussed Connected Health Innovation Centre established at NIBEC.

2. Underpinning research

Enhanced life expectancy and an ageing population are predicted to impose an ever increasing burden on resource-starved healthcare systems worldwide. Innovations in medical technology can offer a cost effective solution in many areas, in particular reducing the labour and resource burden of routine medical observations, as demonstrated through our large MATCH projects [5]. Our research has led to a direct impact in this area through the commercialisation of miniaturised medical devices with remote, wireless, patient monitoring capability.

Following the pioneering work of Pantridge, Adgey and Anderson in mobile coronary care with the invention of the world's first mobile defibrillator, research collaboration over 20 years at Ulster between McLaughlin in sensors, Anderson (d. 2012) in medical electronics and McAdams (Ulster until 2009, currently ENSA-France) in medical electrodes has resulted in the successful development of medical sensors [1], and electro-stimulation devices with over 35 patents licensed.

Our work on developing novel low impedance silver – silver chloride [2] colloid inks customised for flexible substrates [3, 6] and incorporating patented annular designs led to an innovative low cost manufacturing technique that was licensed to Tyco (1998 – 2012) and created the world's largest selling disposable ECG electrode [4]. On the basis of this technology, a spin out company NIRAD Ltd (later Meridian Medical and then Heartscape) was established in 1986. Subsequent NIBEC designs were patented (1994 onwards) and exploited through Heartscape to create a range of telemedicine products, including the Dry Electrode ECG monitor, a Wallet Based ECG System and a dry-electrode Holter monitor. This technology was subsequently licensed to one of the world's first Connected Health companies, SHL Telemedicine Israel, and eventually to Philips Healthcare.

Our research has expanded into the areas of pattern recognition, integrated electronic systems and body worn Wi-Fi and was coupled to novel body sensing techniques for vital signs monitoring based on our electrode fabrication expertise. We focussed on reducing electrode impedance, through Ag-AgCl plasma surface modification [2], and body motion artefacts using a mixture of advanced microfabrication techniques, with a manufacturing focus, and signal processing. For example, MAFF and EU funding supported the development of electrode micro-needles and implantable electrodes that were subsequently patented and licensed to Air Products in 2008.

McLaughlin (currently CTO), Anderson (d. 2012) and McAdams founded Intelesens in 2001 in order to exploit their research and develop products based on the integration of robust algorithms for arrhythmia and motion detection along with impedance-based monitoring of temperature and respiration patterns that utilises a miniaturised wireless (Wi-Fi) chest-worn platform. Since then other patented products have been developed, e.g. chest-worn integrated optics for SpO_2 monitoring, PVDF pulse wave velocity sensors and electronic nose type gas sensor technology.

Our research into advanced medical products based around low impedance electrodes [6], reduced ECG lead sets with associated signal processing and integrated RF electronics was funded through a range of sources such as MRC (PRIME – ECG), EPSRC [5], Wellcome Trust [6], NASA, INI, TSB and joint NSF(US)-SFI(Irl)-DEL(NI) grants. A range of underpinning Centres have been created since 1993, including the £5m IFI Biomedical and Environment Sensors Centre-BEST Centre (joint with four Universities 1997); Centre for Advanced Cardiology Research CACR 2008; the £2mDEL Centre for Intelligent Point of Care Sensors-CIPS 2009 and the £5m Connected Health Innovation Centre- CHIC 2013 [7, 8, 9,10].

3. References to the research

1. Mc Adams, ET; Lackermeier, A; McLaughlin, J; Macken, D; The linear and nonlinear electrical properties of electrode-electrolyte interface; Biosensors and Bioelectronics, 10, 67-74, 1995 - cited 128 times Impact Factor 5.4 DOI: 095656639596795Z
2. C. Escoffier; P. D. Maguire; C. Mahony; W. G. Graham; E. T. McAdams and J. A. McLaughlin; Plasma Chloriding of Thin-Film Silver; A Novel Process in Silver-Silver Chloride Reference Electrode Fabrication: Journal of the Electrochemical Society vol:149 p:H98-H102 (2002) cited 11 times Impact Factor 2.6 DOI 10.1149/1.1457989
3. J A McLaughlin; E T McAdams; J McC Anderson; Profiled biosignal electrode device US 5746207, 1998 (Licensed to Meridian Medical and marketed by Philips)
4. J McC Anderson; E T McAdams; J A McLaughlin "Biosignal Electrode" US5337748, 1994: (Licensed to Tyco Medical and Meridian Medical. Marketed by several leading multinationals including Hewlett-Packard and NDM)
5. J McLaughlin, P. Irwin, Bodily flow measuring system US 6983662 B2, 2001 (Licenced)
6. Swelling and delamination of multi-electrode sensor arrays studied by variable-pressure scanning electron microscopy; P. Lemoine; P. Mailley; M. Hyland; J.M. McLaughlin; E. McAdams; J. Anderson; A. Lynch; D. Diamond; M. Leader; DOI: 10.1002/(SICI)1097-4636(20000605)50:3<313::AID-JBM4>3.0.CO;2-V

Funding

7. Meenan, McLaughlin et. al.; Multidisciplinary Assessment of Technology Centre for Health (MATCH) EPSRC – GR/S29874/01 & EP/F0638221 2003-2013 £5.2m
8. McLaughlin, Anderson; VitalSens vital-signs monitor; Wellcome Trust 084593/Z/07/Z 2008-2010 £410k
9. McLaughlin et. al DEL Cross Border Point of Care Systems 2010 £2m
10. McLaughlin, et. al. InvestNI Connected Health Competence Centre 2012 £5m

4. Details of the impact

NIBEC's fundamental materials research has generated 35 patents and has been translated into a range of advanced commercialised products through technology licensing and, more recently, via a number of Connected Health spin-out ventures**.** These spin-outs currently employ over 150 people and a global impact has been attained with world-wide sales totalling more than £30m per year, with significant benefits to patient wellbeing (numerous lives saved) and reduced costs to healthcare systems for patient care. This success has led to the establishment of the European Connected Health Alliance, led by McLaughlin, which has 150 members including Intel and Bosch and provides a strategic consultation role which impacts directly on NI Government and global business policy. With an award of £5m funding we have established the Connected Health Innovation Centre (CHIC) as an industry-centred competence centre, which focuses on rapidly translating academic research into innovative medical products.

Our spin out companies are Heartsine Inc. *[text removed for publication].* [1], Intelesens Ltd *[text removed for publication].* and partially owned (22%) by GE Healthcare [2, 6, 7, 8] and Heartscape Inc. [3] which was sold to Verathron *[text removed for publication].*. All company products are well-established with full CE and FDA approval. The product portfolio, based on licensed NIBEC patents, includes devices such as PRIME ECG, Vital Signs Wireless Patch, 12-lead holter-telemonitoring, AED defibrillators, telemonitoring platforms, ECG electrodes and a range of algorithms to licensed companies such as Samsung, Tyco and Meridian Medical. In particular, our licensed electrode technology has created the world's best-selling disposable ECG electrode [3], with $70m sales and sold by Tyco, HP, Ludlow and Space Labs, among others. The Automatic Equipment Defibrillator developed with Heartsine, is the most compact AED with an annual turnover of £20m; the telemedicine based 12-lead electrodes systems licensed to SHL Telemedicine has generated $5m sales and a 120 electrode ECG mapping system called PRIME ECG is now selling via Heartscape/Veratron (USA) [3].

Intelesens Ltd, with McLaughlin as current CTO, has developed a miniaturised chest worn platform incorporating wireless, algorithms for arrhythmia and motion detection and impedance-based monitoring of temperature and respiration patterns [8]. After raising over £6.5m of investment, and entering strategic partnerships with Mondo (2005), Intel (2008) and GE Healthcare, who now own a 22% stake (2011), the company now develops a further range of patented products including chest worn SpO_2 monitors, supported by TSB (2012) and pulse wave velocity sensors. *[text removed for publication].* Intelesens and the current 44 qualified staff complement is set to rise as manufacturing is developed worldwide via GE Healthcare, who launched in the US, the Surveillance Carescape 300 Product in May 2013 [2]. In 2011 Intelesens won the prestigious "Most Promising Technology Award" at the 4th Annual Silicon Valley Technology Leaders Awards and in the same year Intelesens was awarded class 2 regulatory approval by the FDA authorities in the USA [6]. Although the company has already around £1m a year turnover, international sales of its defibrillator pad range and V-patch sensor systems is increasing and full commercial realisation is expected in late 2013 when GE Healthcare fully launch the globally FDA approved 'Surveillance Carescape 300', which brings ECG arrhythmia recognition, respiration rate, fall detection, body temperature and heart rate into one wearable platform [2].

HeartSine's development of the world's most compact AED was based on NIBEC's chest impedance and arrhythmia algorithms, in conjunction with novel bi-phasic waveform patterns. This company *[text removed for publication]*, employs 80 people in Belfast and Pennsylvania, has 2 NIBEC licensed patents and is currently exporting to over 40 countries, including the USA [1]. The company has its headquarters in the USA and has been highlighted as a top example of smart portable lifesaving healthcare systems.

Recently one of Heartsines products hit the headlines when it was used in the miraculous survival of former Bolton footballer Fabrice Muamba (2012). HeartSine now manufactures 2,500 units a month and as noted by the Prime Minister David Cameron in recent speeches, its AEDs are to be found in the White House and on AirForce One. They are also favoured by many international airlines, sports bodies and emergency services, from Shell Oil super-tankers to American Airlines and the Singapore EMS service [1, 9].

With McLaughlin as a Director of the European Connected Health Alliance (£500k Collaborative Network & £500k EU), as a member on a number of influential Government Task Forces (Connected Health and Prosperity Board; the NI Connected Health ECO System Board, the Connected Health Innovation Centre Board) and an advisor to Task and Finish Groups on the subject of Connected Health, the expertise derived from NIBEC research and commercial realisation now impacts on core government policy and industry direction within this sector [4, 5]. This work is currently expanding our links with the New York State and the San Diego regions, where similar activities are growing.

The ECHAlliance, which was set up in 2010 to follow-on to the European Connected Health Campus, is an initiative designed to support and promote the wider adoption of healthcare and wellbeing (including sports and fitness) products, services, applications and innovation. In bringing together commercial, academic and healthcare stakeholders, ECHAlliance facilitates focused leadership for the development of 'Connected and MHealth' markets and practices across Europe and beyond. The scope includes the economic development of the full range of eHealth, EHR TeleCare, TeleHealth Telemonitoring and MHealth sectors. At present there are 150 members including Intel and Bosch.

NIBEC, through McLaughlin, in partnership with O'Connor (Chair of the ECHAlliance) have played a pivotal role in establishing Connected Health initiatives in N. Ireland which have directly resulted in an increased focus at ministerial level, an inter-department MOU between our Department of Health and our Department of Enterprise and Trade, changes in policy, expanded government's Connected Health activities and created measurable economic and health benefits over these past 4 years [4, 5]. Over 50 local companies and over 150 organisations (www.ni-chic.org/ni-capability.html) are benefiting from our new ECO system and the associated £10m of recent investments. These benefits include increased employment (e.g. GE Healthcare investments at Intelesens with over 40 jobs), Foreign Direct Investment (e.g. Arc Devices, 10 jobs initially) and the rolling out of new systems such as NI's Patient Record System involving major investment by Orion (15 R&D jobs).

In order to help deliver the impact of our research directly to patient wellbeing and hospital economics, we have established strong links with regional hospital trusts through our Centre for Advanced Cardiology Research, which hosts cardiologist McEneaney as a Visiting Professor. We have established international collaboration through MoUs and formal agreements with e.g. Partners Healthcare (Massachusetts General, USA); CIMIT (Boston) and many other international hospitals. All of this leads to device adoption and the saving of lives which benefits this region significantly. This impact was highlighted recently at the Ulster Business Festival and Investment Conference, chaired by McLaughlin.

Much of the work at Intelesens and Heartsine has been validated by the EPSRC IRC MATCH Centre (Multidisciplinary Assessment of Technology Centre for Health) (BM) and published work demonstrates up to 30% cost savings associated with syncope patients and in the case of AED's key algorithms save the lives of up to 20% more patients [10]. Similar high impact studies have been highlighted in the MATCH Impact Final Report in which Dr Mary Jo Kurth of Randox (www.randox.com) highlighted "The work that MATCH-NIBEC carried out has been critical in demonstrating the value of the diagnostic test and has been widely used in sales presentations and in Randox brochures thus enhancing our sales."

The impact of NIBEC research in Connected Health related disciplines can be summarised as follows:

- Over 150 jobs created across the three NIBEC Connected Health spin-out companies, over £37m of investment and in excess of £30m sales per year.
- Low cost technology for critical care use which saves many lives annually (estimated to be hundreds per year), improves the quality of life, especially for the elderly and cuts costs.
- Enhanced global interest in the possibility of home and hospital based wireless monitoring (e.g. GE Healthcare, Intel investments and 5 recent inward investments)
- Technology uptake by the Wellcome Trust, UK Government, CIMIT (Boston) and various companies as exemplars of the future of healthcare sensor systems.
- New funding and business models are being established which involve strategic partnering with multi-national companies (e.g. GE Healthcare, Intel); best practice techniques for model clinical agreements; platforms for faster FDA and CE approval and encouraging the high quality staff to continuously re-train and develop.
- Moulded the shape of NI Government Strategies, through MATRIX and NI Innovation Strategy panels and inspired a unique MoU between Department of Health (NI) and Department of Enterprise and Trade in NI.

Our research has highlighted the value of tri-lateral partnerships with industry (local and international) and clinicians which will establish market and clinical roadmaps for each product family along with field testing and rapid feedback.

5. Sources to corroborate the impact

1. Heartsine: Letter of Evidence and Support CH1
2. Intelesens: Letter of Evidence and Support CH2
3. Heartscape Letter of Evidence CH3
4. European Connected Health Alliance: Letter of Evidence CH4
5. Dept. of Trade and Investment (Minister Foster) Letter of Evidence CH5
6. Intelesens Media: http://www.intelesens.com/news/110408_mostpromisingtechnologyaward.php CH6
7. Intelesens Media: http://www.intelesens.com/news/101101_irishtimesfeature.php CH7
8. Intelesens Media: http://www.bbc.co.uk/news/technology-11396798 CH8
9. Heartsine Media: http://www.heartsine.com/en/about/timeline CH9
10. MATCH Impact Media: http://www.match.ac.uk/MATCH_Finale/MATCH_Impact_report_Influence_on_health_industry_and_policy.pdf CH10