Institution: University of Sussex

Unit of Assessment: 12 – Engineering

Title of case study: Enabling the development of novel sensor devices for medical, transport safety and forensic use

Period when the underpinning research was undertaken: 2000 – 2016

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Robert Prance	Professor of Sensor Technology	1980 – 2016
Daniel Roggen	Professor of Sensor Technology	2014 – current

Period when the claimed impact occurred: 2013 – 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Novel sensors for the remote detection of electrical signals produced at the University of Sussex have resulted in technology to track human heart rate and respiration without the need for physical contact with the body. They have been built into devices used in healthcare, transport safety and forensics. Since 2013, work to commercialise the research has generated and safeguarded [text removed for publication] jobs at Plessey Semiconductors, and accumulated sales of sensor technology totalling [text removed for publication]. The University has also earned more than [text removed for publication] in licence fees, royalties and associated payments.

2. Underpinning research

The Sensor Technology Research Centre at the University of Sussex undertakes advanced research projects orientated towards the needs of industry and other third-party organisations. Comprising academics working on wearable technologies (Roggen), and fundamentals of sensor technology (Prance), the Centre invented and developed a new type of device – the Electrical Potential Sensor (EPS). The EPS effectively works as a highly sensitive electrometer that amplifies and measures changes in electric fields, including those created by the human body. The technology contrasts with the more common electromagnetic sensors, which instead detect the variation in magnetic fields. Electric potential sensors are capacitively coupled ultra-high impedance electrometers with an internally stabilised bias current. This makes them electrically robust and simple to use; unlike other electrometer technologies, they require no set-up or in-use adjustments to achieve stability.

Prance's pioneering work developed the sensors and demonstrated how they could obtain electrical signatures of heart and respiratory rates whilst being held up to a metre away from a fully clothed person [3.1]. No electrical or mechanical contact between the sensor and the subject was required. The sensor effectively acts as a perfect voltmeter: it can obtain signals and produce readings of electrical activity without the need to pass real current between the sensor and the object being measured. When the sensors are held on the fingertips, ECG (electrocardiogram) data of quality high enough for clinical use are obtained through insulated electrodes via capacitive coupling only. The group's first paper describing these two new measurement techniques with their sensor [3.1] won the Institute of Physics Measurement Science & Technology "Best Paper" award, as the most downloaded in 2002.

Prance's group then went on to develop a method to reject external electronic interference at the signal processing stage, removing the need to shield subjects when taking the measurements. This development enabled accurate biometric measurements, including respiration and heart rate, to be made remotely even when the subject was seated next to computer equipment [3.2].

After demonstrating that such signals could be obtained without the need to connect electrodes or through any other bodily contact, Prance, Roggen and others then showed that they could analyse the signals — and the way they changed — to identify and track people's movements and positions remotely [3.3-3.5]. The researchers also demonstrated that the sensors could find so-called electrostatic fingerprints – the electrical charge deposited when a finger touches a thin insulating surface. The results showed the technique was sensitive enough to identify an individual from their electrostatic fingerprint, and also to estimate reliably the time when the fingerprint was left behind [3.6].

3. References to the research

3.1 C J Harland, T D Clark, R J Prance. Electric potential probes - new directions in the remote sensing of the human body, *Measurement Science and Technology* 13 (2002), 163-169 https://doi.org/10.1088/0957-0233/13/2/304

3.2 R J Prance, ST Beardsmore-Rust, P Watson, C J Harland, H Prance. Remote detection of human electrophysiological signals using electric potential sensors. *Applied Physics Letters* 93 (2008) https://doi.org/10.1063/1.2964185 selected for 'Virtual Journal of Biological Physics Research', 1 Aug. (2008), www.vjbio.org

3.3 H Prance, P Watson, R J Prance, S T Beardsmore-Rust. Position and movement sensing at metre standoff distances using ambient electric field. *Measurement Science and Technology* 23 (2012), 115101, https://doi.org/10.1088/0957-0233/23/11/115101

3.4 D Roggen D, A P Yazdan, F J Ordóñez Morales, R J Prance, H Prance. Electric field phase sensing for wearable orientation and localisation applications. In: *Proceedings of the 2016 ACM International Symposium on Wearable Computers* (2016) pp. 52-53. https://doi.org/10.1145/2971763.2971774

3.5 A Pouryazdan, R J Prance, H Prance, D Roggen. Wearable electric potential sensing: a new modality sensing hair touch and restless leg movement. In *Proceedings of the 2016 ACM international joint conference on pervasive and ubiquitous computing: Adjunct* (2016) Sep 12 (pp. 846-850). https://doi.org/10.1145/2968219.2968286

3.6 P Watson, R J Prance, S T Beardsmore-Rust, H Prance. Imaging electrostatic fingerprints with implications for a forensic timeline. *Forensic Science International* 209 (2011), e41–e45, https://doi.org/10.1016/j.forsciint.2011.02.024

Key research grants

G1. EPSRC. Development & application of an array-based scanning electric potential microscope. GR/M52212/01. £321,466. 1999-2003. Co-I: R Prance.
G2. RCUK. Basic Technology Award: The development of electric potential sensors as generic tools for basic technology. GR/R87550/01. £1,033,868. 2002-06. PI: R Prance.
G3. EPSRC. The electric potential sensor - a basic technology for measurement science. EP/E042864/1. £893,000. 2007-11. PI: R Prance.
G4. Innovate UK (TSB). Innovation Award. R/TSB/2406. £224,324. 2013-15. PI: R Prance.
G5. European Union. Devices for NeuroControl and NeuroRehabilitation (ENIAC JU). 324257-2. £136,075. 2013-16. PI: R Prance.

4. Details of the impact

Enabling Plessey Semiconductors to develop and market innovative sensor devices

A wide range of practical applications have emerged from the research to develop the pioneering sensors described in Section 2. Much of this impact has been generated through a commercial relationship with the company Plessey Semiconductors, which bought exclusive rights to develop, apply, and sell the sensor technology under licence from the University of Sussex. The relationship led to the first integrated-circuit version of the EP sensor being produced, and this was subsequently marketed as the Electric Potential Integrated Circuit (EPIC). [text removed for publication] of Plessey Semiconductors confirms:

> *"This initial research and IP, together with continued collaboration, was instrumental in Plessey's subsequent development of an award-winning range of novel sensor products, the Electric Potential Integrated Circuit (EPIC)."* [5.1a].

In addition to enabling this "*significant advance*" in Plessey's capacity for product development, the collaboration has also led to economic benefits:

> "*The EPIC Business line is estimated to have safeguarded and created of the order of [text removed for publication] jobs at the company. During the period 2013 to 2019, Plessey invested [text removed for publication] in technology development, market analysis and business development, gaining traction in a number of applications and achieving revenue in excess of [text removed for publication] … The EPIC technology… enable[d] us to establish important engagements with a few major strategic companies world-wide across several products and applications, including [text removed for publication]. Some unique processing technology was developed and through a five-year period it permitted Plessey to maintain and establish a wider technology/electronics integration group which continues today in the support of a major partnership with [text removed for publication]."* [5.1a].

Through its agreement with Plessey, the University of Sussex has earned more than [text removed for publication] in license fees, royalties and other associated payments from the technology [5.2], and Plessey's commitment to its development was further indicated by their meeting of consumable and sensor costs, as well as an in-kind contribution of [text removed for publication] in staff time. The patents covering the technology are extensive, including Europe, USA, Japan, Germany and France, demonstrating the significant reach of the IP [5.3].

Many of the terms and details of this agreement with Plessey, including their customers, are commercially sensitive and confidential. But real-world applications based on the research outlined in [3.1-3.3] have generated "*revenues [that] included:*

- *Car seat demonstrator kits to tier one automotive suppliers and EOMs*
- *single lead ECG devices into several NHS Trusts, 30 devices comprising a major trial within the [text removed for publication] Health Authority*
- *EPIC device sales into several early-stage product developments in the healthcare sector, including [text removed for publication] and numerous start-ups.*" [5.1a].

Devices produced by Plessey using the EPIC sensor technology include a fully certified single lead electrocardiogram (ECG) product called imPulse^{TM} for use by non-specialists in GP surgeries [5.1b]. With no need for skin preparation, use of conducting gel, or accurate electrode positioning, the imPulse monitor made it easier and quicker for healthcare workers to acquire high-quality clinical data with minimal training. For example, one consultant cardiologist confirmed that: "*Having performed an initial test of imPulse lead-one ECG device, it is clear that this device is able to provide and record a usable single lead ECG similar to lead 1 of a 12-lead ECG*" [5.10].

ImPulse was also one of five devices included in an NHS-funded project that delivered 6,000 mobile ECG units to GP surgeries, clinics and pharmacies in 2018 [5.5]. Professor Gary Ford, Stroke Physician and lead on the project for the Academic Health Science Networks (AHSNs), said:

> *"We have highly effective treatments that can prevent these strokes, but early detection is key. Using cost-effective technology, the NHS will now be able to identify people with irregular heart rhythms quickly and easily. This will save lives… Today's new devices are just one example of the way that low-cost tech has the potential to make a huge difference."* [5.5].

Individual AHSNs have also worked directly with Plessey, providing support for the regional evaluation and adoption of imPulse. For example, the Deputy Director of Innovation & Growth, West of England AHSN, confirmed:

> *"Colleagues in primary and secondary care have welcomed imPulse's potential to improve the patient experience and give reassurance in rapidly capturing quality ECG signals. The interactions between Plessey staff and frontline healthcare practitioners have benefitted all parties as practitioners help to shape novel products that work in real healthcare settings."* [5.10].

An NIHR review commissioned by NICE (National Institute for Health and Care Excellence) on the clinical and cost effectiveness of ECG devices in primary care concluded that the use of seven devices, including imPulse, "*appears to be a cost-effective use of NHS resources*" [5.4a]. A subsequent trial conducted by the Exeter Clinical Trials Unit, with 217 participants from one large hospital in Devon, found that "*Atrial fibrillation was diagnosed in 45 out of 215 individuals who had ECG traces and 42 out of 199 individuals who also had an imPulse measure*" and that it "*worked particularly well at higher heart rates (above 80 beats per minute)*". Additionally, "*the imPulse device demonstrated superior specificity to pulse palpation, with higher positive predictive values, thus suggesting the potential to reduce referral for confirmatory ECGs in non-AF cases, if used instead of pulse palpation*." Since ECGs are "*expensive, time consuming and usually require a separate appointment,*" the study concluded that "*the imPulse device could therefore be used to screen for atrial fibrillation and reduce the number (and therefore cost) of ECG referrals and time taken to diagnose atrial fibrillation*." [5.4b]

ImPulse's contributions in the medical technology sector have also been recognised through a number of awards; for example, Plessey (for imPulse) won the National Technology Awards 2017 in the "Healthcare Technology of the Year" category [5.11a], and was shortlisted for the Elektra Awards 2016 in the "Excellence in Product Design for Medical" category [5.11b].

Vital sign monitoring using the sensor technology is also valuable in other sectors, including the motor and airline industries, which face increasing regulatory pressure to detect when drivers and pilots are not alert. Of direct relevance to Plessey was the production of an armband heartrate device with woven flexible electrodes. This formed part of a project with Nottingham Trent University [5.9] and contributed to the development of the WARDEN^{TM} – a novel seatback device featuring a driver alertness monitor, which assesses heartrate and breathing. The technology was showcased and discussed at industry events including the Paris Motor Show in 2016 [5.7] and Geneva Motor 2017.

In 2019, the US company [text removed for publication] bought the sensor products and relevant IPR from Plessey for an undisclosed amount. [text removed for publication] intends to develop the technology for a broader market and this will extend the impact of the research further. [text removed for publication] is currently negotiating its licencing agreement with the University of Sussex. [text removed for publication] is well placed as a US-based medical instrument company to access the vital US markets and has a proven record of obtaining US venture capital funding.

Expanding the applications and beneficiaries of Sussex EPS technology

In 2019, the Sensor Technology Research Centre was approached by [text removed for publication], who subsequently invested in work to produce a non-contact fingerprint scanner for use in [text removed for publication]. A key advantage of the EPS technology in this application is that it is completely non-invasive and so does not preclude the use of other analysis techniques after a fingerprint has been imaged. In addition, EPS makes it possible to estimate the time elapsed since the fingerprint was deposited, which conventional techniques cannot achieve. [Text removed for publication] [5.8].

Further collaborations have arisen for the sensors' application in the medical sector, beyond those described above. The EPS technology is now being used by the charity Rockinghorse, with the Trevor Mann Baby Unit at Brighton and Sussex University Hospitals Trust, to develop a novel sensory heart rate monitor that midwives and neonatal staff can use with new-born babies. The charity anticipates that the 'Neo-sense' device will "*provide a non-invasive, reliable and quick-to-administer solution to measure the heart rate of a baby… during [their] first minute of life*." Ethical approval and funding are under preparation for a pilot study of the technology planned for later this year [5.6].

5. Sources to corroborate the impact

5.1 a) Letter from [text removed for publication], Plessey Semiconductors; b) Plessey Semiconductors Ltd EPIC Sensor Applications Guidebook (PDF)
5.2 Plessey – University of Sussex transaction data. Excel file available on request.
5.3 Patent documentation (EP1451595, EP2002273, EP2047284, EP2174416, DE60232911.6, DE602007038199.1, DE602007015657.2, DE602008041572.4, US7885700, US8264247, US8054061, US8860401, US8923956, JP5777082, JP5676102 and JP4391823) (PDF)
5.4 a) Duarte et al (2019), 'Lead-I ECG for detecting atrial fibrillation in patients attending primary care with an irregular pulse using single-time point testing: A systematic review and economic evaluation' *PLoS ONE* 14(12) https://doi.org/10.1371/journal.pone.0226671
b) Rhodes et al (2019), 'imPulse: Sensitivity and specificity of a novel mobile lead-I ECG-like device for the detection of atrial fibrillation' (Under review, supplied as PDF).
5.5 'NHS rolls out new tech nationally to prevent 3,650 strokes, save 900 lives and £81 million annually'. Digital Health London (23/02/2018). https://digitalhealth.london/nhs-rolls-new-tech-nationally-prevent-3650-strokes-save-900-lives-81-million-annually/
5.6 Rockinghorse Children's Charity. Recently funded projects webpage: https://www.rockinghorse.org.uk/about-us/our-projects/recently-funded/
5.7 'Plessey and Segula embed heart-rate monitor in car seat at Paris Motor Show'. Vehicle Electronics (29/09/2016) https://vehicle-electronics.biz/news/plessey-and-segula-embed-heart-rate-monitor-car-seat-paris-motor-show/1181
5.8 Letter from [text removed for publication].
5.9 Announcement of Technology Strategy Board funding by Advanced Textiles at NTU (22 June 2014) https://ntuadvancedtextiles.wordpress.com/2014/06/22/tsb-award/
5.10 The AHSN Network. Case Study on imPulse™: portable ECG monitor https://www.ahsnnetwork.com/case-study/impulse
5.11 a) National Technology Awards 2017 https://www.retail-systems.com/rs/Eblasts/NationalTechAwards2017WinnersBrochure/NATWinnersBrochure.pdf b) Elektra Awards 2016 https://www.electronicsweekly.com/news/elektra-awards-news/elektra-awards-2016-2016-11/