Institution: Aston University

Unit of Assessment: 12 Engineering

Title of case study: ECG-derived biosignals for improved healthcare outcomes and a Real-time Adaptive Predictive Indicator of Deterioration (RAPI+D)

Period when the underpinning research was undertaken: 2015-2020

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:
Dr Randa Herzallah	Senior Lecturer ASTUTE	2014-present
Professor David Lowe	Professor	!994-2019

Period when the claimed impact occurred: 2015-2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

Aston research led to product improvements in adult and paediatric healthcare after novel algorithms developed through two industrially-funded projects – the ECG-Derived Biosignals Project and RAPID – were implemented into a commercial system developed by world-leading digital healthcare company, Isansys. The algorithms work by collecting, processing and analysing real-time data from cardiac activity. The algorithms have led to innovation in Isansys's products. Specifically, they have:

- Improved Isansys' method of deriving respiration rate.
- Led to FDA certification of Isansys' PSE monitoring system for commercial exploitation in the US.

Led to pending clinical trials, which could lead to the wider international uptake of this capability and improved patient care.

2. Underpinning research

Aston's research into control algorithms [**R1,R2**] enables one set of sensors to extract important physiological parameters which otherwise would be measured using invasive methods and large amounts of equipment and wires attached to the patient. Instead of this more invasive technique, the algorithms use advanced signal processing and filtering techniques to analyse signals routinely monitored on hospital wards, such as Electrocardiograms (ECG), Photoplethysmograms (PPG) and Seismocardiograms (SCG), to extract the required physiological data.

The complex algorithms that enabled this were developed as part of the ECG-Derived Biosignals project, a collaborative venture between Aston University and Isansys, a world-leading digital healthcare company. These algorithms are now embedded in Isansys's wireless Patient Status Engine (PSE) – "the most complete, scalable and simple-to-use advanced patient monitoring platform", which monitors patients automatically and in real time.

Embedded in Isansys's PSE, the algorithms help enable the PSE to extract physiological indicators including respiratory rate [**R3,R4**], heart rate, and key R, Q and T peaks [**R3,R5**]. The PSE can then alert healthcare professionals to potential problems, enabling them to intervene quickly and potentially save lives.

The research has also developed a novel measure of breathing distress – Work of Breathing (WoB). While existing methods for measuring breathing distress are invasive and require multiple measurements, the ECG-Biosignals project's unique technique is non-invasive and utilises routine ECG recordings. While this measure has yet to be included in the Isansys PSE, it will be the subject of forthcoming clinical trials.

Aston's research – through the RAPID project with Birmingham Children's Hospital – also developed a Paediatric Early Warning Score (PEWS). Also embedded in Isansys's PSE, this assesses the correlation between extracted physiological indicators, and alerts clinicians to potential problems. This facilitates early intervention and aims to save the lives of children and young people [**R6**].

3. References to the research

R1 Herzallah, R 2015, 'Fully probabilistic control for stochastic nonlinear control systems with input dependent noise', Neural Networks, vol. 63, pp. 199-207. https://doi.org/10.1016/j.neunet.2014.12.004

R2 Herzallah, R & Zhou, Y 2020, 'A Tracking Error Based Fully Probabilistic Control for Stochastic Discrete Time Systems with Multiplicative Noise', JVC/Journal of Vibration and Control. https://doi.org/10.1177/1077546320921608

R3 Kozia, C, **Herzallah, R & Lowe, D** 2018, Adaptive R-peak Detection Using Empirical Mode Decomposition. in International Conference on Time Series and Forecasting, ITISE 2018. International Conference on Time Series and Forecasting, ITISE 2018, Granada, Spain, 19/09/18 https://research.aston.ac.uk/en/publications/adaptive-r-peak-detection-using-empirical-mode-decomposition

R4 Kozia, C, **Herzallah, R & Lowe,** D 2019, ICA-Derived Respiration Using an Adaptive R-peak Detector. in International Conference on Time Series and Forecasting: ITISE 2018: Theory and Applications of Time Series Analysis. Springer, pp. 363-377, International Conference on Time Series and Forecasting, ITISE 2018, Granada, Spain, 19/09/18. https://doi.org/10.1007/978-3-030-26036-1_25

R5 Kozia, C, **Herzallah, R & Lowe**, D 2019, ECG-Derived Respiration Using a Real-Time QRS Detector Based on Empirical Mode Decomposition. in TA Wysocki & BJ Wysocki (eds), 12th International Conference on Signal Processing and Communication Systems. ICSPCS 2018., 8631760, IEEE, 12th International Conference on Signal Processing and Communication Systems, ICSPCS 2018, Cairns, Australia, 17/12/18. https://doi.org/10.1109/ICSPCS.2018.8631760

R6 Duncan, H, Fule, B, Rice, I, Sitch, A and **Lowe D**, 2020 'Wireless monitoring and real-time adaptive predictive indicator of deterioration', Scientific Reports, 10, 11366, https://doi.org/10.1038/s41598-020-67835-4

4. Details of the impact

The research led to the development of novel algorithms for the non-invasive extraction of physiological indicators to help clinicians and nurses intervene swiftly and save lives. All Aston algorithms are now embedded in Isansys's Patient Status Engine (PSE) – the WoB algorithm is subject of forthcoming clinical trials.

The methods and techniques Aston developed were tested on real data from 982 patients provided by Birmingham Children's Hospital (BCH) in 2018/19. All data were provided with reference values against which the extracted measures were checked.

The results [**R4, R5**] proved to be more accurate and reliable than those previously recorded by Isansys's devices, achieving 99.8% accuracy in QRS detection, 81% accuracy in the WOB

estimation and a mean absolute error (the mean error between the actual and estimated values) estimation of just 0.4 in the breathing rate.

A Consultant from Birmingham Children's Hospital's Paediatric Intensive Care Unit, said: "*This technology is truly transformational. For the first time it allows us to analyse patients' data in real time in the same way that various other high risk industries have done for years.*" [**S1, S2**]

Because the algorithms obtain the measures non-invasively by analysing a hospital patient's routinely monitored ECG signals [**R3, R5**], they reduce patient discomfort and the number of sensors required. Through the Paediatric Early Warning Score (PEWS) they also enable health professionals to be alerted quickly to potential issues.

The Consultant said: "*The ability to track and identify deterioration towards a cardiac arrest will give doctors the chance to save the patient's life.*" [**S3**]

The algorithms have had the following impacts:

- The algorithms have been embedded in Isansys's PSE, improving the quality of the company's medical devices [**S3**] and particularly their ability to measure respiration rate. The Isansys Chief Executive, said: "*Respiration rate is a difficult vital sign to measure accurately. We are therefore very pleased to report that one of the early outputs from the ECG-Derived Biosignals project was an improvement to our current method of deriving respiration rate… Feedback from other users has been very positive and no issues about the accuracy of the respiration rate functionality have subsequently been recorded in our post market surveillance reports.*"
- The algorithms have also led to the Isansys PSE's FDA certification for commercial exploitation in the US [**S4**]. The CEO of Isansys said: "*Since the inclusion of these Aston developed improvements to the algorithm in the PSE, we have been able to meet the rigorous requirements of the US FDA 510(k) procedure and as a result the PSE is now certified for commercial exploitation in the USA.*"
- The algorithms have now led to pending clinical trials of Aston's novel Work of Breathing (WOB) measure (currently on hold due to the COVID-19 pandemic). Monitoring breathing distress is currently invasive and expensive, so a clinically-proven, automatic WoB measure derived from ECG signals would reduce treatment costs and the number of staff required to monitor patients. The CEO of Isansys said: "*We expect the new automatic WOB (Work of Breathing) measure … to yield very promising results. Trials were envisaged to commence at Birmingham Children's Hospital to enable the earlier detection of potential life-threatening adverse events using real-time data, instead of relying on post processing of lab test and other data held in the patient's electronic medical record… Isansys intends to undertake these trials with existing hospital customers both in the UK and overseas. However, all planned studies are now on hold as a result of the Covid-19 pandemic.*" [**S4**]
- The algorithms and their incorporation into Isansys's devices could have huge commercial implications. The CEO of Isansys said: "*Ideally, every patient in hospital would be continuously and automatically monitored. In practice hospitals deem around 60% of their patients need to be monitored in this way. For the UK alone, this figure is around 12 million patients annually and globally hundreds of millions. The total patient monitoring market is therefore many £billions and the market leaders will be those companies whose systems and devices provide the most accurate and trustworthy data. The ECG-Derived Biosignals project with Aston University will stand us in very good stead to maintain a leading position.*"

Aston's algorithms and alarm system are also integrated into Isansys's wireless Lifetouch device, which connects to the PSE. This wearable device can be attached to the chest and ankle to measure and analyse vital signs in real time. This kind of non-invasive, individual monitoring provides real-time accurate information about the patient, potentially leading to faster treatment, lives saved and reduced hospital stays. The mother of one of the patients said: "*I'm so pleased that [my child] was*

able to take part in the study. I think the wireless technology is great, I can pick him up more easily and he is constantly monitored [**S1**]."

5. Sources to corroborate the impact

S1 Milestone for Isansys monitoring tool. March 16, 2017. https://www.buildingbetterhealthcare.co.uk/news/article_page/Milestone_for_Isansys_monitoring_tool/126946

S2 Wireless technology breathes new life into medical practices https://www.birminghamhealthpartners.co.uk/wireless-technology-breathes-new-life-into-medical-practices/

S3 Isansys: wireless technology helps to save children's lives. November 12, 2015. https://www.gov.uk/government/news/isansys-wireless-technology-helps-to-save-childrens-lives

S4 Isansys Lifecare Ltd support letter. June 22 2020.