Institution: University of Oxford

Unit of Assessment: 15, General Engineering

Title of case study: UOA15-06: Vital sign monitoring for hospital patients

1. Summary of the impact

Visensia™ is a bedside 'early warning' system, deployed in many hospitals in the UK and US, which automatically analyses hospital patients' vital signs, produces simple-to-read scores, and alerts healthcare staff to any deterioration in a patient's condition. It resulted from research in this Department, commercialised by Oxford BioSignals Ltd (£1.5m sales to date, and 137 licences sold since 2010). Visensia™ reduces the number of patients already in hospital who suffer an unexpected cardiac arrest or need an unplanned transfer to intensive care. The US Food and Drug Administration (FDA) approved the system's use after a 1000-patient clinical trial. There were no unexpected fatal cardiac arrests on the wards where the clinical trial took place in the three years after Visensia™. was deployed.

2. Underpinning research

The research underpinning this software-based system took place between 1993 and 2005. Initial advances in novelty detection (the ability to detect patterns outside the boundaries of a model of normality) provided the foundation for developing new algorithms that could monitor and analyse vital signs.

- In 1993, with his research group, Prof. Lionel Tarassenko (who joined the Department in 1988 as University Lecturer and has been Professor of Electrical Engineering since 1997) developed a new approach to novelty detection methods for signal processing. Working with Professor Stephen Roberts, he used a Gaussian mixture model to characterise a training set of normal data [1] before using novelty detection to identify cases of epileptic seizures in recordings of electrical activity in the brain. Collaborating with Professor Sir Michael Brady (who joined the Department in 1985 and retired in 2010), he then extended the method with localised, non-parametric models of normality to learn a description of normal breast tissue in mammograms [2]; possible mass-like structures (*i.e*. cancerous tumours) were identified by novelty testing against this description.
- Between 1995 and 2002, Tarassenko's research successfully secured EPSRC support through two grants (see Section 3). This enabled the new techniques to be developed further and applied to two fields: (i) monitoring jet engine health (in collaboration with Rolls-Royce); (ii) monitoring hospital patients' vital signs (initially with Oxford Instruments). In the second of these areas, novelty detection was applied to data fusion of the five vital signs (heart rate, respiratory rate, oxygen saturation, blood pressure and temperature), aiming to give an early warning of deterioration in acutely ill patients outside intensive care. A five-dimensional model of normality was learnt from hundreds of hours of data collected from patients connected to bedside monitors, enabling development of a 'patient status index'.
- In 2002, the University of Oxford filed a patent application to protect the Intellectual Property underpinning this new approach to patient monitoring; patents were duly granted in the US, Europe, Australia and Japan [3]. The first clinical trial of the system was carried out at Oxford's John Radcliffe Hospital from 2003 to 2005 [4], closely followed by an independent clinical trial in the US from 2006 to 2009 that resulted in the system securing FDA approval for its early warning capabilities in 2008 (see Section 4).
- In 2007, Tarassenko extended his research on vital sign monitoring to paediatrics, using kernel regression to model the effect of age (from birth to 18 years) on heart rate and respiratory rate – the two most important vital signs in children [5].
- Translating the technology to a hospital environment also prompted Tarassenko to design evidence-based Early Warning Scores for less acute patients. This solution harnessed the

routine observations of vital signs made every 8 or 12 hours by nurses on general wards. Between 2009 and 2011, Tarassenko and his team developed an algorithm enabling nurses to calculate a simple numerical 'score' reflecting a patient's condition [6], which is now used throughout the Oxford University Hospitals (OUH) Trust (see Section 4).

3. References to the research (best indicators of research quality are marked ***'Q'***)

1. Roberts, S.J. and Tarassenko, L. 'A Probabilistic Resource Allocating Network for Novelty Detection' (1994). *Neural Computing* 6(2), pp 270-284, http://dx.doi.org/10.1162/neco.1994.6.2.270 ***'Q'***
2. Tarassenko, L., Hayton, P., Cerneaz, N. and Brady, J.M. 'Novelty Detection for the Identification of Masses in Mammograms' (1995). *4th International Conference on Artificial Neural Networks*, Cambridge, UK, 26-28 June 1995, pp 442-447, http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=00497860
3. Tarassenko, L. and Townsend, N.W. 'Patient Condition Display'. US patent 7,031,857, European patent EP1389948, Japanese patent JP4391089, Australian patent AU 2002 257964, https://www.google.com/?tbm=pts#q=EP1389948&tbm=pts
4. Tarassenko, L., Hann, A. and Young, D. 'Integrated Monitoring and Analysis for Early Warning of Patient Deterioration' (2006). *British Journal of Anaesthesia*, 97(1), pp 64-68, http://dx.doi.org/10.1093/bja/ael113 ***'Q'***
5. Fleming, S., Thompson, M., Stevens, R., Heneghan, C., Plüddemann, A., Maconochie, I., Tarassenko, L. and Mant, D. 'Normal Ranges of Heart Rate and Respiratory Rate in Children from Birth to 18 Years of Age: A Systematic Review of Observational Studies' (2011). *Lancet*, 377(9770), pp 1011-1018, http://www.susz.me.uk/pubs/Fleming2011_Lancet.pdf
6. Tarassenko, L., Clifton, D.A., Pinsky, M.R., Hravnak, M.T., Woods, J.R. and Watkinson, P.J. 'Centile-based Early Warning Scores Derived from Statistical Distributions of Vital Signs' (2011). *Resuscitation*, 82(8), pp 1013-1018, http://dx.doi.org/10.1016/j.resuscitation.2011.03.006 ***'Q'***

Grants supporting this research (both awarded to Prof. Lionel Tarassenko)

- EPSRC: Fundamentals of Novelty Detection, 1995-1997, £169k (GR/K51334/01)
- EPSRC: Fundamentals Aspects of Novelty Detection, 1998-2002, £164k (GR/M05614/01)

4. Details of the impact

Since 2008 Tarassenko's research has led directly to a cut in mortality rates, through its delivery of methods effective in alerting healthcare staff to patient deterioration in the hospitals where those methods are now deployed. Patients are key beneficiaries, but so too are healthcare staff whose jobs have been made easier and less stressful, since they can concentrate most of their efforts on the highest-risk patients (as triaged by Visensia™ score). Moreover, through sales, the research has also generated valuable economic benefits.

The need for these methods is clear. Around 13 million people are admitted to acute hospitals each year in England and Wales alone. Some inevitably die due to their illnesses, but across the UK, better care could reduce significantly mortality from:

- Approximately 23,000 in-hospital cardiac arrests*, where currently the survival rate is just 15% to 25%**.
- Approximately 20,000 admissions of in-hospital patients to intensive care units: the mortality rate for these is reported as 50%, compared with 35% for other patients admitted to the same units***.

In 2005, the National Confidential Enquiry into Patient Outcome and Death (NCEPOD) estimated that sub-optimal care on wards contributed to around one third of the deaths there.

Health Impact – better healthcare in UK and US hospitals

Extensive evidence proves that patients experiencing an adverse event such as a cardiac arrest show abnormal physiology in the hours preceding the event, and that early intervention improves patient outcomes****. In 2007, the UK's National Patient Safety Agency (NPSA) reported that a key action to improve patient safety was "to identify patients who are deteriorating and act early".

Integrating vital sign parameters into a novelty detection framework has, through continuous bedside monitoring, provided early warning of adverse events in acutely ill patients outside intensive care. The Clinical Investigator for the independent clinical trial in Pittsburgh, leading to FDA approval stated publicly: "there were no unexpected cardiac arrests for three years on the wards in which Visensia™ was deployed" [7]. Between 2008 and 2012, Visensia™ was installed in 12 UK and US hospitals (e.g. St. Mary's Health Care Hospital, Michigan [8]) and is still being used in all of them.

In addition, the Early Warning Scores developed by Tarassenko and his team now form the basis of evidence-based 'track and trigger' observation charts used to monitor (and so optimise care for) all 800,000 patients treated each year in adult general wards in every acute hospital within the OUH Trust [9]. Since the introduction of the charts, the number of cardiac arrests per annum across the Trust has fallen by 10% [10].

Economic Impact – commercial success, wealth generation

In 2007, Oxford University licensed the novelty detection algorithms to Oxford BioSignals. (In 2009, Oxford BioSignals became OBS Medical – www.obsmedical.com). As noted above, Visensia™, the commercial version of the system, is already securing practical take-up in hospitals. Pivotal to this commercial success was independent evaluation in the 1000-patient trial at a 24-bed Step-Down Unit (SDU) in the University of Pittsburgh Medical Center (UPMC):

- Phase 1 assessed whether Visensia™ would have enabled earlier intervention by the Medical Emergency Team (MET – the 'crash team') in cases of severe patient deterioration. Results showed that the system would have detected all major events with respiratory and/or cardiac causes with an average advance detection time of 6.3 hours (*i.e.* Visensia™ would have alerted staff to the deterioration, on average, 6.3 hours earlier than the time at which the MET was actually called) [11].
- In Phase 3, Visensia™ was used to alert SDU nursing staff to major abnormalities in patients' vital signs. This led to a substantial reduction (from 18.9% to 11.1%) in the number of patients becoming critically unstable for a sustained period of time. The number of unexpected deaths also fell from six in Phase 1 to zero in Phase 3 [12, 13].

  As a result of this success, the system was kept in operation at the SDU when the trial ended.

One of the Visensia™ monitors deployed at the bedside in the UPMC SDU during the trial that provided clinical evidence crucial to securing FDA approval.

Phase 1 of the trial provided the clinical evidence necessary to secure FDA approval for Visensia™ to be used as an adjunct to a patient monitor. Phase 3 provided the evidence to secure FDA approval for Visensia™ to be used as real-time alerting software for critical care.

The system is now the only FDA-approved index for combining multiple physiological parameters [14]. In 2008, it won Frost & Sullivan's North American Central Stations Patient Monitoring Technology Innovation Award [15]. From 2008 to 2012, take-up of Visensia™ in UK and US hospitals generated total sales amounting to around £1.5 million for OBS Medical [16].

References for Section 4 only:

* Smith, G.B., Prytherch, D.R., Schmidt, P., Featherstone, P.I., Knight, K., Clements, G. and Mohammed, M.A. 'Hospital-wide Physiological Surveillance – A New Approach to the Early Identification and Management of the Sick Patient' (2006). *Resuscitation*, 71(1), pp 19-28. http://dx.doi.org/10.1016/j.resuscitation.2006.03.008

** Sandroni, C., Nolan, J., Cavallaro, F. and Antonelli, M. 'In-hospital Cardiac Arrest: Incidence, Prognosis and Possible Measures to Improve Survival' (2007). *Intensive Care Medicine,* 33, pp 237-245. http://dx.doi.org/10.1007/s00134-006-0326-z

*** McGloin, H., Adam, S.K. and Singer, M. 'Unexpected Deaths and Referrals to Intensive Care of Patients on General Wards – Are Some Cases Potentially Avoidable?' (1999). *Journal of the Royal College of Physicians, London*, 33(3), pp 255-259 http://www.ncbi.nlm.nih.gov/pubmed/10402575

**** Kause, J., Smith, G., Prytherch, D., Parr, M., Flabouris, A. and Hillman, K. 'A Comparison of Antecedents to Cardiac Arrest, Deaths and Emergency Intensive Care Admissions in Australia and ANZ, and the UK – the ACADEMIA Study' (2004). *Resuscitation*, 62, pp 275–282. http://dx.doi.org/10.1016/j.resuscitation.2004.05.016

and

Quach, J.L., Downey, A.W., Haase, M., Haase-Fielitz, A., Jones, D. and Bellomo, R. 'Characteristics and Outcomes of Patients Receiving a Medical Emergency Team Review for Respiratory Distress or Hypotension' (2008). *Journal of Critical Care*, 23, pp 325-331. http://dx.doi.org/10.1016/jcrc.2007.11.002

5. Sources to corroborate the impact

7. Presentation to the 8th International Conference on Rapid Response Systems and Medical Emergency Teams. Royal College of Physicians, London, 12th May 2013. (Corroborates the impact the device had in relation to cardiac arrests on wards - presentation held on file)
8. http://www.innovations.ahrq.gov/content.aspx?id=1786 (Study and evaluation of the use of VisensiaTM at St. Mary's Health Care Hospital, Michigan, confirming they are still using it.)
9. http://www.ouh.nhs.uk/about/publications/documents/annual-report-2012.pdf (OUH Annual Report 2012, confirming the number of patients treated annually by the OUH Trust.)
10. Information from Chair of the OUH Trust's Recognising the Acutely Ill and Deteriorating patients (RAID) Committee. (Corroborates that the number of cardiac arrests per annum across the Trust has fallen by 10%)
11. Hravnak, M., Edwards, L., Clontz, A., Valenta, C., DeVita, M.A. and Pinsky, M.R. 'Defining the Incidence of Cardiorespiratory Instability in Patients in Step-Down Units Using an Electronic Integrated Monitoring System' (2008). *Archives of Internal Medicine*, 168(12), pp 1300-1308. http://dx.doi.org/10.1001/archinte.168.12.1300 (Details of the Phase 1 trial at the UPMC.)
12. Hravnak, M., DeVita, M.A., Clontz, A., Edwards, L., Valenta, C. and Pinsky, M.R. 'Cardiorespiratory Instability Before and After Implementing an Integrated Monitoring System' (2011). *Critical Care Medicine*, 39(1), pp 65-72. http://dx.doi.org/10.1097/CCM.0b013e3181fb7b1c (Details of the Phase 3 trial at the UPMC.)
13. http://www.regenerativemedicine.net/NewsletterArchives.asp?qEmpID=715&qCat=USN (Newsletter article on the UPMC clinical trials.)
14. http://www.reuters.com/article/2008/09/24/idUS195122+24-Sep-2008+BW20080924 (Press release confirming FDA approval for Visensia™.)
15. http://www.frost.com/prod/servlet/press-release.pag?docid=149543299 (Article on the OBS Medical Technology Innovation Award)
16. Information provided by OBS Medical, corroborating the total generated sales.