Institution: University College London

Unit of Assessment: 13 – Electrical and Electronic Engineering, Metallurgy and Materials

Title of case study: Adoption of Senceive's innovative remote condition monitoring solutions in the rail and construction industries

1. Summary of the impact

UCL spinout company, Senceive Ltd, has established itself as an innovative provider of wireless enabled remote condition monitoring solutions. The company provides a robust, scalable, safe and highly cost-effective infrastructure monitoring capability for railway and construction industry applications, with customers including Amey, Costain, Network Rail and Tubelines. Recent deployments on projects such as Crossrail have been recognised by industry bodies as delivering significant product innovation and cost savings in excess of £1 million compared to use of a wired monitoring solution.

2. Underpinning research

The research underpinning this impact case study was undertaken in the Department of Electronic and Electrical Engineering from 2003 to 2005 by Dr Lionel Sacks, a Lecturer in the Information and Communication Systems Group and Dr Matthew Britton, a post-doctoral research fellow in the same research group. It arose as part of a Department of Trade and Industry (DTI)-funded project entitled SECOAS (Self-Organising Collegiate Sensor Networks) in which UCL was a participant along with industrial partners BT Exact PLC, Intelisys Ltd and Plextek Ltd, and the Universities of Essex and East Anglia. The objectives of the project [1, 2] were to demonstrate how a distributed network of smart sensors could be configured through the development of decentralised algorithms, such that the resulting sensor network would automatically adapt to failures, upgrades and requirement changes. Importantly, practical validation of the resulting technology took place through a trial deployment at the Scroby Sands wind farm located off the Norfolk coast.

UCL's significant contribution to the SECOAS project was the development of an Integration Service Layer (ISL), which consisted of a lightweight operating system and modules for interfacing between the sensors, communications layers and processing systems that reside on each wireless node. Figure 1 illustrates schematically the basic approach, where sensor components, supported by microcontroller-based devices, are networked and managed to form a system capable of performing remote asset monitoring. It used design rules inspired by biological automata or agents which interact with their neighbours via simple rules whilst also co-operating with a large number of individuals to perform complex global tasks; the basis of these concepts were presented at the premier sensor networks venue in 2005 [3, 4]. This was crucial to the resulting mesh-network communications architecture being both highly robust to the changes in topology that could occur due to node failures, obstacles placed in radio paths and varying weather conditions, and extremely scalable. The use of distributed approaches to network management [2, 3] enabled each node in the mesh-network architecture to be truly self-organising and autonomous, and as a result, avoided installation complexities arising from the use of explicit routing nodes in wireless monitoring approaches based upon Zigbee (IEEE 802.15.4) communication protocols. By the conclusion of the project, the SECOAS project partners had demonstrated [5] that it was feasible to combine the UCL ISL with cheap off-the-shelf hardware and software components in order to provide a wireless-enabled asset-monitoring solution that had potential for use in environmental and industrial monitoring applications.

The translational objectives of the DTI's Next Wave programme funding also resulted in a series of market assessment activities being undertaken as the project team sought to understand the commercial potential of the project's research outputs. These activities indicated that owners of rail, utility and industrial infrastructure were seeking to monitor the state of their assets in a more efficient and robust manner. For example, Sir Ian McAllister (then Chairman of Network Rail) cited that his organisation was investing tens of millions of pounds in 'intelligent infrastructure' programmes, as they sought to deliver effective predictive maintenance programmes that would enable railway operators to be informed when problems with often ageing and remote assets were likely to occur, and thus enable better planning for future investment. Resulting benefits would include the ability to maintain high availability of transportation networks, a reduction in operational problems, delays and associated economic consequences, and also increased safety both for

passengers and railway workers. Back in 2005, wireless-enabled remote condition monitoring technologies showed promise, but a limiting factor to adoption was that the solutions needed to be robust, scalable and cost-effective in line with expectations of users who were highly conscious of safety and reliability. With the early prototypes of the UCL technology satisfying such requirements, the decision was made to commercially exploit the UCL technology through the creation of a spinout company, Senceive Ltd, which was founded in November 2005. In January 2006, Dr Britton became a full-time employee of Senceive in order to assist in the translation of the UCL technology into a commercial product, whilst Dr Sacks provided consultancy support to the company post-incorporation.

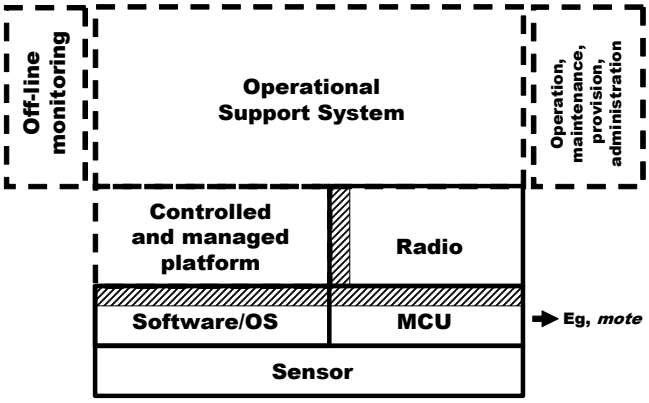

Figure 1: The four layers of the UCL system: (i) sensor components, (ii) the software, operating system and microcontroller unit (MCU); (iii) radio and network control and management system; and (iv) the operational support system, administration, provision and maintenance. Layers (iii) and (iv) together comprise an Integrated Service Layer (ISL).

3. References to the research

1. The SECOAS Project: Development of a Self-Organising, Wireless Sensor Network for Environmental Monitoring. M. Britton and L. Sacks. Second International Workshop on Sensor and Actor Network Protocols and Applications, August 2004, Boston, Massachusetts, USA. http://www.cs.kent.ac.uk/projects/secoas/papers/SANPA-2004-Britton.pdf {26 citations - Google Scholar)
2. A Self-Synchronised Scheme for Automated Communication in Wireless Sensor Networks, A. Gonzalez-Velazquez, I.W. Marshall and L. Sacks. Proceedings of IEEE Conference on Intelligent Sensors, Sensor Networks and Information Processing, ISSNIP' 2004, Melbourne, Australia. http://doi.org/crhtf7 {11 citations – Google Scholar}
3. A Biologically-Inspired Approach to Designing Wireless Sensor Networks, M. Britton, L. Shum, L. Sacks and H. Haddadi. European Conference on Wireless Sensor Networks. January 2005. Istanbul, Turkey. doi: http://doi.org/fsw8xk {17 citations – Google Scholar}
4. A Biologically-Inspired Clustering Algorithm Dependent on Spatial Data in Sensor Networks, I. Wokoma, L. L. Shum, L. Sacks, and I. Marshall. European Conference on Wireless Sensor Networks. January 2005. Istanbul, Turkey. http://doi.org/fdzf2n {27 citations – Google Scholar; 61 downloads from IEEEXplore since Jan. 2011}
5. Engineering for Real – The SECOAS Project. I. W. Marshall, A. E. Gonzalez, I. D. Henning, N. Boyd, C. M. Roadknight, J. Tateson, and L. Sacks. Workshop on Software Engineering Challenges for Ubiquitous Computing. University of Lancaster, June 2006. http://ubicomp.lancs.ac.uk/workshops/seuc2006/ {26 citations – Google Scholar}

References [1], [3] and [5] best demonstrate the quality of the research.

The SECOAS project was funded by the UK Department of Trade and Industry (DTI) as part of the Next Wave Technologies and Markets programme, with the UCL element consisting of £105,300 of funding for research activities that were undertaken during the period January 2003 to April 2005.

4. Details of the impact

In the years since its formation, Senceive Ltd has established itself as the preferred provider of

wireless remote condition monitoring for geotechnical and railway projects in the UK, leading to significant **commercial benefits for both Senceive and its customers**. The company's Flatmesh product range – launched in May 2009 and based upon UCL-developed wireless mesh technology – provides a highly robust, reliable and easy-to-deploy asset monitoring solution. Flatmesh enables the **owners of geotechnical, rail and construction infrastructure to accurately and efficiently monitor their highly valuable and often difficult to access assets** and in a manner which is significantly more cost-effective compared to alternatives such as manual monitoring, wired solutions or emerging technologies such as fibre optics. The innovative nature of the Senceive monitoring solution has been widely recognised, with for example a high-profile Tunnelling product innovation award being secured in November 2012 [a].

The impact of adopting the Senceive solution for monitoring projects is illustrated through a 2011 deployment at Bond Street underground station [b], which was undergoing a £300m major redevelopment with the objective of increasing capacity, improving accessibility and creating an interchange with Crossrail. In the design phase of the project, a need was identified for grouting works to be undertaken in voids that had formed around the Jubilee Line tunnel linings in order to stabilise the tunnels prior to commencement of the station reconstruction works. Early in the project, it became clear that a highly flexible, safe and reliable system to monitor movement within existing tunnels during the grouting works was needed, given the risks to personnel and tunnelling infrastructure if attempts were made to pump significant amounts of excess grout into the voids. A solution was delivered which utilised Senceive's high-resolution wireless tilt meters mounted on tunnel lining segments using novel magnetic fixings, with individual rotational and linear equivalent movements being displayed on Senceive's Webmonitor software. Halcrow's Associate Director Tunnels said of the project: *"*There was simply no credible solution other than that developed with Senceive. **The system made significant savings** to the cost of the works, which would have been much more labour-intensive, time-consuming and slower if a mechanically fixed wired solution had been used" [c]. Tunnelling Journal estimates that the Senceive solution saved an estimated £1 million compared to conventional techniques [d]. The Innovation Director at Costain, another partner on the project, said: "Remote monitoring is an important service we are providing to our customers. It reduces costs compared to traditional methods and allows our teams to **remotely monitor assets safely** during construction and through the life of the asset. Remote monitoring is all about providing intelligent solutions to our customers to **enhance their business performance** and **reducing the cost of infrastructure delivery**. We are pleased to be able to support Senceive to bring innovation to make our delivery more efficient" [c].

More recent deployments include a major tunnel re-lining project in 2012/13 on the Jubilee Line between Bond St and Baker St, where Senceive was retained directly by Tubelines due to the company's unique ability to satisfy the challenging project-monitoring requirements imposed by remedial works that needed to be undertaken efficiently during limited periods (i.e. evenings and selected weekends) when trains did not run. The problem that Senceive was assisting in resolving was covered by BBC News [e] and in respect of the Senceive solution, the Lead Tunnel Engineer at Tubelines said: "Flatmesh and its enhanced integrated communications hub is an innovative, unique and appropriate combination of leading-edge technologies, developed by Senceive and specifically adapted for tunnelling applications. It offers the opportunity for a "totally wire-free solution" from tunnel to surface for challenging short- and long-term engineering works for which there is **no credible existing alternative**" [f].

In addition since 2012, Amey has used Senceive's solutions on an increasing number of sites to deliver a structural monitoring capability for their UK-wide Civil Examination Framework Agreement (CEFA) contract for Network Rail. [text removed for publication]. Finally, in July 2013, Senceive secured a major contract with Canary Wharf Contractors to provide an underground tunnel monitoring system on the Northern and Bakerloo Lines, as part of the Shell Centre re-development project taking place on London's South Bank. The significance of this contract was that **Senceive's solution displaced competing monitoring approaches** ranging from laser-based electronic theodolites (feasibility issues due to space constraints), fibre-optics (expensive and unproven) and wired solutions (expensive and inflexible) [h] and thus provided strong and timely evidence of the impacts that wireless monitoring can deliver to the geotechnical and railway industries**.**

The overall commercial opportunity that Senceive is addressing in the rail and construction markets is of significant economic importance, with the Institute of Civil Engineers (ICE) estimating that the UK alone will spend around £50 billion per annum until 2030 [i] to address historic underinvestment, deliver new projects such as HS2 and transition to a low-carbon economy. The utilisation of Senceive's wireless remote asset monitoring platform by supply chain partners such as Amey, Costain, Balfour Beatty Rail and Getec (part of the Keller Group) **enables companies to secure significant competitive advantages** when tendering for construction and maintenance contracts at home and overseas. More broadly, wireless sensor network technologies remain an area of significant commercial interest, with market research reports (e.g. IDTechEx [j]) predicting that the market for wireless sensor network solutions will grow from around $0.45 billion in 2011 to around $2 billion by 2021.

Finally from an **economic impact** perspective, Senceive is a small but increasingly important contributor to the growth of the knowledge-based economy in London. The company has achieved its success after a relatively modest investment, having raised £450,000 of seed investment together with grants from the London Development Agency & Technology Strategy Board of £220,000 during the REF impact period. Company turnover has risen consistently over the past three years, with the year to 31 July 2013 generating revenues in excess of £600,000 (a four-fold increase on 2012), whilst from an employment perspective, the company currently employs eight graduate or higher level staff (2 in 2007) from offices located in Putney, London [h].

5. Sources to corroborate the impact

[a] Senceive won Product / Equipment Innovation of the Year at the 2012 International Tunnelling Awards – http://www.tunnellingawards.com/540057

[b] Article in May/June 2013 Tunnelling Journal (pages 40-46) describing the Jubilee Line remediation project for which Senceive provided the tunnel monitoring solution. http://viewer.zmags.com/publication/63a5c32d#/63a5c32d/41

[c] Halcrow's Associate Director Tunnels confirms the advantages of Senceive monitoring solution and the Innovation Director at Costain PLC confirms that Senceive's remote monitoring enhances business performance and reduces the cost of infrastructure delivery. http://www.senceive.com/wp-content/uploads/2012/12/Press-Release-Int-Tunnelling-Award.pdf

[d] £1m saving reported in Tunnelling Journal, April/May 2013, p.40 http://bit.ly/17uMsBn

[e] For the problems affecting the Jubilee Line, which Senceive is helping resolve, see "Jubilee Line repair work spread over months", BBC News 29 April 2013, http://www.bbc.co.uk/news/uk-england-london-22340598

[f] A statement from the Tubelines' Lead Tunnel Engineer's statement confirms there is no credible existing alternative to Senceive's Flatmesh for monitoring in tunnels. Available on request.

[g] [text removed for publication]

[h] A statement from the CEO of Senceive Ltd confirms the contract for the Shell Centre re-development through Canary Wharf Contractors together with details of investment raised and employment figures. Available on request.

[i] The ICE's assessment of the rail and construction infrastructure market: http://www.tunneltalk.com/ICE-Nov10-Presidential-address.php

[j] The growth in the market for wireless sensor network solutions: IDTechEx: Wireless Sensor Networks 2011-2021. http://www.idtechex.com/research/reports/wireless-sensor-networks-2011-2021-000275.asp