Institution: Loughborough University

Unit of Assessment: B11 Computer Science and Informatics

Title of case study: Enhanced products and services through low-cost wireless solutions

1. Summary of the impact (indicative maximum 100 words)

Low-cost wireless solutions beyond the technologies available previously and developed at Loughborough University since 2005 are used by IDC, and Sure, who integrate these technologies in several products and services so generating impacts in terms of:

- Increased awareness of industry and service providers of new wireless monitoring and control technologies
- Development of new products and services which have improved operational efficiency
- Economic benefits downstream of the products and services.

The technologies have been deployed in a logistics distribution centre (ToysRUs), an automotive manufacturing process (Toyota), and a safety and security system (Sure).

2. Underpinning research (indicative maximum 500 words)

Funded by EPSRC (2000 – 2001) and Royal Society (2004-2005), Prof. Shuang-Hua YANG (2000-present) pioneered Internet–based monitoring and control research which resulted in large number of publications, among which references **[3.1]** and **[3.2]** are key ones. The research findings provided a systematic design method, a unique canonical system structure, and solutions for various design specifications. The work was graded as "international leading" by EPSRC. The demonstrator system won the Creativity Award in the 2005 International Exhibition Contest on Digital Signal Processing in Taiwan. Reference **[3.1]**, cited 181 times so far, was the first major publication to detail the systematic design methodology and seamlessly integrated together computer science and control engineering for this new type of control system. The research monograph **[3.2]** is considered by those in the field to be pioneering in the area of introducing the Internet into remote control and monitoring. The solutions proposed by the book lay the foundation and the best practice for remote monitoring and control of industrial plants and other important infrastructures.

The work was extended by YANG and his research team and applied to remote integration of distributed systems over the Internet environment **[3.3]** funded by the Ministry of Defence (MoD) via SSEI (Software System Engineering Initiative) Programme in 2008-2010, in collaboration with BAE Systems. This research project developed techniques and a framework to allow multiple system development teams to collaborate over the Internet on the integration, testing and maintenance of complex high-integrity real-time embedded software systems. The solution allowed in-service systems/software to be monitored and maintained remotely, thus reducing the need for on-site customer support.

The work was also extended from wired to wireless technologies, and applied to building fire safety protection **[3.5]**, dwelling energy saving **[3.6]**, logistic distribution centre, and automotive manufacturing plant since 2005, consecutively funded by Technology Strategy Board (TSB) (2006-2009, 2007-2009), Carbon Connections (2008-2009), ERDF (European Regional Development Fund, 2011-2012), EPSRC (2010-2014) via the projects (Yang acting as Principal Investigators) as outlined in Section 3. These projects designed wireless sensor networks (ZigBee and/or 6LowPAN based), seamlessly connected them with the Internet, and finally implemented remote monitoring and control functions for various applications with the support of low-cost wireless sensor network technologies. The outcomes of these projects include a variety of design capabilities of wireless sensor networks, commercialized product-like prototypes of various wireless devices and system/embedded software, prototypes of energy harvesting devices, and mobile object indoor location tracking approaches. The work on smart home won the 2010 Institute of Measurement and Control (InstMC) Honeywell Prize. The innovative wireless radiator valve was patented and demonstrated in Ecobuild 2011 in EXCEL in London.

3. References to the research (indicative maximum of six references)

References to the Internet-based monitoring and control research are:

3.1. Yang, S. H., Chen, X. and Alty, J.L., 2003, Design Issues and Implementation of Internet Based Process Control, *Control Engineering Practice*, 11(6), 709-720, DOI: 10.1016/S0967-0661(02)00181-8

3.2. Yang, S.H., 2011, *Internet-based control systems*, Springer, ISBN: 978-1-84996-358-9

References to the remote integration of distributed systems over the Internet are:

3.3. Wang, Y.H., Yang, S.H., Grigg, A., and Johnson, J., 2009, A DDS Based Framework for Remote Integration over the Internet, 7th Annual Conference on Systems Engineering Research 2009 (available at http://cser.lboro.ac.uk/papers/S08-54.pdf).

References to the wireless technologies for building fire safety protection, dwelling energy saving and automotive manufacturing plants are:

3.4. Yang, S. H., 2013, *Wireless Sensor Networks*, Springer, ISBN: 978-1-4471-5504-1

3.5. Yang, S.H., and Frederick, P., 2006, SafetyNET/ A wireless sensor network for fire protection and emergency responses, *Measurement and Control,* 39(7), 218-219, DOI: 10.1177/002029400603900704

3.6. Gill, K. and Yang, S.H., 2009, A Zigbee-based home automation system, *IEEE Transactions on Consumer Electronics*, 55(2), 422-430, DOI: 10.1109/TCE.2009.5174403

The following grants received by Yang as PI (unless indicated) financially supported the above underpinning research:

Period	Grant title	Sponsor	Peer review/R&D competition	Value
2001-2002	Design of Internet-based control systems	EPSRC	Peer review	£63k
2004-2005	Interface design for large-scale systems using formal methods	Royal Society	Peer review	£7200
2006-2009	Secure Ad Hoc Fire & Emergency Safety Network (SafetyNet)	TSB	R&D competition	£320k
2007-2009	Integration and Demonstration of Energy Efficient Dwelling Networks (IndeedNET)	TSB	R&D competition	£150k
2008-2010	Framework for Distributed Development and Integration	MoD	Competition	£200k
2009-2010	Demonstration of Energy Efficient Central Heating Systems in the Home Environment	Carbon Connections	Competition	£72k
2011-2012	Low-cost wireless tracking system for motor manufacturing, storage and delivery	ERDF	Competition	£45k
2010-2014 (Co-I)	Low effort energy demand reduction	EPSRC	Peer review	£1.3m

4. Details of the impact (indicative maximum 750 words)

The impact of Loughborough research on wireless monitoring and control technologies is increasing the awareness of industrial collaborators of new wireless technologies, equipping them and public audience with the capabilities, leading and working with the industrial collaborators

converting/integrating Loughborough low-cost wireless solutions into commercial products and services so creating economic benefits. These technologies have been disseminated in the form of product-like prototypes, demonstration systems, technical reports, and seminars. The end-users of our technologies include an automotive manufacturer (Toyota UK in Derby), a logistic distribution centre (Toys R Us in Coventry), domestic households (through Sure Technology), and a technical service provider (IDC, Derby). The significance of the impact is providing low-cost wireless network enabled capability of monitoring and control to a wide range of applications including mobile object tracking, fire safety detection, home energy saving.

Pathway to impact

We have been running two project websites since 2006, (www.indeednet.org) and (www.firesafetynet.org.uk) which have attracted significant number of enquiries from industry. We produced a newsletter and a DVD for fire safety protection and distributed it to the emergency response community. We also demonstrated our wireless domestic radiator valve controller at Ecobuild 2011, Excel in London, March, 2011. The SafetyNET was presented as a keynote to the TIEMS (The International Emergency Management Society) 17th Annual Conference 2010 in Beijing. It was also presented to Chinese industries in the UK-China IoT Tech-transfer event in Shanghai and Wuxi in December 2011, jointly organised by Technology Strategy Board and Chinese local governments. The home automation and energy harvesting system was presented to Masterclass- wireless sensor networks, RTLS and active RFID and Energy Harvesting & Storage Europe 2011 in Munich in June 2011. See the link (http://www.idtechex.com/events/presentations/energy-efficient-hardware-design-for-wsn-nodes-002850.asp).

Beneficiaries:

Three technical service providers, Yang's industrial collaborators, have directly benefited from the underpinning research:

IDC (Intelligent Distributed Control) Limited, a Derby based SME, was a pure project service provider for niche applications within manufacturing and logistics and had no wireless development ability before collaborating with Yang's group. IDC recognised the benefits of the wireless sensor networking technology being proposed by Yang which eliminated the need for wires and cables between control modules, as a natural enhancement for the Simplicon product range **[5.1]**. In collaboration with Yang, IDC embarked on a 5 year programme in 2010 to develop a wireless platform for industrial applications and have since produced over 20 products based on ZigBee WSN (www.zig-bee.co.uk). These products are now being used in Toyota, Toys R Us, Boots, and other sites throughout Europe. IDC could be considered the UK leader in ZigBee based industrial applications. Over the last 5 years IDC's annual turnover is approximately £1.0m per year with 80% of business generated on the success of its ZigBee related projects. Working with Yang's team IDC is now jointly developing a low-cost wireless tracking system for industrial applications in Stockyards, Warehousing and Manufacturing facilities with several interested large end users which include Toyota Manufacturing, DHL, Toys R Us and other European companies. IDCs 5 year business plan, based on WSNs is expected to deliver £10M over the next 4 years.

Sure Technology, a Nottingham based SME, was a stand-alone security products provider for domestic markets. Participating in the research of SafetyNET and IndeedNET led by Yang, Sure Technology now is able to provide a high level of experience in networked interactive building management systems and energy saving products for temperature and lighting control. See the link (http://technology.sure24.net/index.php?r=site/page&view=partners) Benefiting from these new capabilities Sure Technology now provides the solutions in "remote communication of devices over wireless networks and the Internet for: home automation, building automation, temperature and facility management, building management and temperature monitoring", which is far beyond their traditional business. The company IP valued less than £100k before collaborating with Yang (2006) and now values more than £1m increased by 10 times. The IP value increase is mainly contributed by the development of their wireless technology based new products and services **[5.2]**.

5. Sources to corroborate the impact (indicative maximum of 10 references)

The following sources of corroboration can be made available at request:

5.1. A letter has been obtained from IDC Limited stating the benefits gained from working with Yang and the impact

5.2. A letter has been obtained from Sure Technology stating the benefits gained from working with Yang and the impact