Institution: Liverpool John Moores University

Unit of Assessment: UoA16

Title of case study: Impact of research into non-invasive sensors on industrial applications

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

Sensors and on-line monitoring systems have clear benefits for various sectors including water utilities, food, health, safety and defense. Current approaches include optical, acoustic, mechanical, electrical and bio sensors, however they often suffer from low reliability, sensitivity and accuracy, combined with infrequent measurements and high cost, all of which hinders their industrial application. Hence, to meet the current industrial demand the scientists at the Built Environment and Sustainable Technologies (BEST) Research Institute have developed a new real-time non-invasive sensor platform based on the use of electromagnetic waves. These are being used extensively by United Utilities PLC, Mechan Controls PLC, the UK Defence Science & Technology Laboratory and Animalia in Norway.

2. Underpinning research (indicative maximum 500 words)

The sensor industry has generated over £50 billion in revenue worldwide in 2011-12. Although uptake of sensors by industry has increased significantly there remains a number of hindrances which include: failure to match industrial requirements; poor links between available sensor technologies and quality regulations; verification schemes do not sufficiently match industrial practices; challenge of managing large data quantities and translating them into meaningful information for operational processes. To address these issues, our approach has been to develop a novel real-time non-invasive sensor platform based on electromagnetic waves. This platform operates at variable frequencies, and can be tuned to suit the industrial requirements based upon cross-sector application. This case study outlines examples of these applications, namely from the water, food and defence sectors.

- **Water quality:** Since 2011, Korostynska (EU research Fellow), Mason (Reader) and Al-Shamma'a (BEST Director) have developed a unique sensor for water quality monitoring meeting the demands of the EU Water Framework Directive. The sensor platform [ref 1 and 2] has the capability to perform real-time assessment at point-of-source locations without the need for the biological and chemical laboratory use. The sensor has the capability of measuring the water's physical characteristics (e.g. pH, temperature, conductivity) and chemical parameters (e.g. oxygen, alkalinity, nitrogen and phosphorus compounds) efficiently and reliably. The research was funded via the EU FP7 programme (grant 1 in [6]) in collaboration with United Utilities. Associated work in 2012, supported by the TSB and led by Al-Shamma'a and Shaw (Reader), resulted in the development of a non-invasive hybrid sensor (acoustic and electromagnetic wave) for the detection of water leaks in underground networked water pipes. This project was led by Balfour Beatty (grant 2 in [6]). This project covers the design, development and commercialisation of an innovative internal leak detection and condition assessment system for use within both potable water and dirty water pipework networks. JD7, a UK based pipeline inspection company, is currently testing and evaluating the sensor for worldwide exploitation. This success has led to further international collaboration with RIKEN-Japan, funded by the Daiwa Anglo-Japanese foundation (grant 3 in [6]) to develop a non-invasive sensor meeting the needs of the water industry, particularly in respect of monitoring nuclear contamination.
- **Food quality:** In 2012, Al-Shamma'a and Mason were awarded funds by the Norwegian Research Council (grant 4 in [6]) to develop, for the first time, a non-invasive sensor to be deployed in the food industry for real-time quality control. No previous research and development or commercial sensor system has been able to measure water holding capacity, tenderness, foreign objects or bacterial contamination in real time at low cost and with accuracy that makes its implementation acceptable to the food industry. Working in collaboration with food companies from Norway (Animalia and Nortura) and Spain (Faccsa and CICAP), this project has been focussed towards improving the quality of meat sold in

supermarkets by determining tenderness, in addition to detection of foreign objects, including bacteria. A particularly important development of this work has been to reduce the time required for the current gold standard of quality control (i.e. the EZ Driploss Test) from 24-hours to just 20 minutes.

- **Food safety:** There are various types of non-contact safety switches available in the market however, there is unmet demand for an electronic stainless steel enclosed non-contact safety interlock switches for use in harsh environments and high pressure wash down areas. Research at the Institute 2011-2013, covered the design, simulation and prototype demonstrator of various safety switches magnetic sensors, in collaboration with Mechan Control resulted in the development of frequency operated non-contact stainless steel switch and actuator for the food industry [ref 4] and (grant 5 in [6]). Furthermore, by analysing the material composition of the sensor enclosure, it was found that non-magnetic 316 stainless steel has almost zero carbon content and a specific percentage of Nickel, which aids transmission and propagation of the particular frequency signal between switch and actuator.
- **Defence structure integrity:** A team comprising of Al-Shamma'a and Mason were awarded a research contract 2009-2012 by the UK Defence Science & Technology Laboratory (dstl) to develop a system for determination of filter residual life in gas masks (grant 6 in [6]). The team developed for the first time a sensing method which could non-invasively determine the age of an activated carbon product [ref 5]. The success led to a further award (grant 7 in [6]), led by Mason and Al-Shamma'a, to assess the potential of the sensing platform for structural health monitoring in military vehicles. Furthermore, the researchers are currently collaborating with Redrow, in applying similar sensors in the construction industry.

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

[1] O. Korostynska, A. Mason and A.I. Al-Shamma'a, "Flexible microwave sensors for real-time analysis of water contaminants", Journal of Electromagnetic Waves and Applications, vol. 27, Issue 16, pp: 2075-2089, 2013. doi:10.1080/09205071.2013.832393.

[2] O. Korostynska, A. Mason and A. I. Al-Shamma'a, "Monitoring Pollutants in Wastewater: Traditional Lab Based Versus Modern Real-Time Approaches," in A. Mason and S. Mukhopadhyay (eds), "Smart Sensors for Real-Time Water Quality Monitoring", Springer, Ch. 1, pp. 1-24, 2013, ISBN: 978-3-642-37005.

[3] O. Korostynska, R. Blakey, A. Mason, and A. Al-Shamma'a, "Novel method for vegetable oil type verification based doi: 10.1016/j.sna.2012.12.011, 2013.

[4] M. Farrah and A. Al-Shamma'a, "Behavior of low frequency signal through stainless steel enclosures in noncontact safety switch application", IEEE Sensors Journal, vol. 13, issue 1, 299-305, 2013, doi: 10.1109/JSEN.2012.2212429.

[5] A. Mason, O. Korostynska, S. Wylie, and A. I. Al-Shamma'a, "Non-destructive evaluation of an activated carbon using microwaves to determine residual life", Carbon, doi: 10.1016/j.carbon.2012.06.034, it is available on line.

[6] **Research Grants:**

No.	Title	Source	Value	Year
1	Multi Sensor Fusion for Real-time Monitoring of Waste Water Quality (Water-Spotcheck). PI (Al-Shamma'a)	EU	€270k	2011-2013
2	SAVE Water (Subaqua Assessment Vehicle for Water Infrastructure). PI (Al-Shamma'a)	TSB	£420k	2012-2014
3	Real-time monitoring of nuclear contamination of water through sensors fusion. PI (Mason)	Daiwa Foundation	£10k	2012-2013
4	Increased Efficiency: Moving from Assumed Quality	EUREKA	€520k	2012-2014

	to Online Measurement and Process Control (INFORMED). PI (Al-Shamma'a)			
5	Development and characterisation of stainless steel safety switches. PI (Al-Shamma'a)	Mechan Controls	£110k	2010-2013
6	Residual Life Monitoring of Activated Carbon. PI (Al-Shamma'a)	dstl	£186k	2009-2012
7	Development of a compact low power EM wave based health monitoring system for military platforms. PI (Mason)	dstl	£38k	2012-2013

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

The advances in sensor technologies made by BEST contribute to new technology, product development and their adoption in a number of industrial sectors including food, water and defence. The niche research work has been extremely successful in attracting funding at national and international levels to solve industrial challenges, a trend which looks set to continue.

The hygienic safety issue in the food industry for example [ref 4], has proven that stainless steel switches eliminate the danger of food contamination where there is a possibility of plastic switches being smashed and entering the food chain. The use of stainless steel switches, 2012, allows them to be robust and provides them with the ability to withstand harsh environments (e.g. temperature, ingress and high pressure steam cleaning). This has enabled Mechan Controls PLC to develop innovative products which have been commercially successful 2012-2013, considerably raising their international market income and attracting further investment partners. This has resulted in a fully deployed sensor system in Proseal food machines, Alton Towers Fairground Safety, London Eye carriages and Japanese rail. Since 2013, the company has sold 2,072 units of the Magnasave Safety product (product code MS8-SS-21-DC-05M) with total revenue of £103,270.

The success of the product particularly in the food industry has been a result of the significant benefits it affords. Namely, the use of stainless steel has a positive environmental impact since it reduces waste, enables greater product shelf-life and reduces manufacturing down-time resulting from damaged switches which contaminate food products. Furthermore, the reduced down-time enhances overall productivity, saves energy and ensures supply chain reliability, along with continued affordability to customers.

The Technical Director of Mechan Controls PLC states: *"The success of the research was tremendous for our core business and now the safety standards are calling for greater integrity in the safety provision, which is pushing the whole safety market, especially non-contact devices, for high value products that have greater complexity and reliability. This will certainly put Mechan products to the forefront of any competitor markets".*

Continuing from the success of work in the food industry, work with Animalia and Nortura in Norway has led to the application of our unique sensor platform, 2011-2013, to replace a current industry gold standard, the EZ Driploss Test, for meat quality. The current test is manual, requiring a cut of meat and a 24 hour period to assess the quality; our system, developed in 2012, can reproduce this in a 20 minute time period. Currently the system is undergoing industrial trials in Norway by Animalia, and has significantly improved their capacity to test meat quality at various points in the meat processing chain which has allowed them to identify areas of improvement. Of particular importance is water loss from meat as it impacts on tenderness and saleable value; for every 1% of water lost in a single Nortura processing plant it is estimated to cost approx. €100,000 per day.

The Senior Research Scientist at SINTEF states: *"The sensor system developed at LJMU has proven to be ideal for the meat industry and looks set to become the new gold standard for meat quality indication which will help inform meat processing improvements and ensure a high standard of meat being delivered to consumers".*

Applying the developed sensing expertise to other sectors, a significant example has been the water industry, 2011-2013. Current analytical techniques require the attendance of a technician to

acquire water samples for off-site laboratory analysis. This approach has a significant disadvantage - the sample taken represents only the condition of the sample at the time of sampling or testing. It is a snap-shot. Online based sensors are coming to the mark, but the cost of such sensors is high and the range of measurable parameters is limited. The Technology Development Manager of United Utilities said: *"The developed real time non-invasive electromagnetic wave sensors by LJMU have certainly helped us in determining the quality of water with consistency and high repeatability in real time without the need for the biological and chemical laboratory testing."* The importance of such sensors is underlined by the EU Water Framework Directive, which regulates the permissible contaminant levels in water; failure to comply results in significant financial penalty.

Our novel sensor platform was also adapted, 2011, to study activated carbon in gas masks, successfully resulting in the only automated method for monitoring activated carbon residual life. The Technology Development Manager of dstl said: *"The success of such a sensor has certainly reduced the time taken for the conventional chemical test to a few minutes, as verified by a 9 month study. The work has resulted in significant transfer of knowledge from LJMU, and we are adopting such sensor techniques in our activities at Porton Down".* The UK has in excess of 200,000 active military personnel, a considerable number of whom will require the use of a gas mask during active duty. The current policy is to exchange gas masks based on a fixed time interval which does not consider actual use. This policy leads to significant waste as masks are often replaced without being used. However there is the possibility that some masks become contaminated and are therefore rendered useless prior to this fixed replacement interval. Therefore, the impact of this research is a significant cost saving in needless replacement of gas masks, in addition to potentially saving the lives of personnel equipped with contaminated masks.

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

1. Technical Director, Mechan Controls PLC can confirm the tremendous success of the research, development and unit sales of the non-contact Magnasave Safety switches product and reliability.
2. Senior Research Scientist, SINTEF, Norway can confirm the niche and unique electromagnetic wave sensor system developed at LJMU and its impact on the meat industry.
3. Head of Division, Animalia, Norway, can confirm the niche and successful deployment of the real time, non-invasive electromagnetic wave sensor in the meat industry leading the way to revolutionise the industrial quality assurance assessments methods.
4. Technology Development Manager, United Utilities, can confirm the real time non-invasive LJMU unique sensor for the water industry.
5. Technology Development Manager, Ministry of Defence, can confirm the use of LJMU's novel sensor platform to investigate the condition of activated carbon in gas masks.
6. Mechan Controls, Company Website, Product Information for Magnasafe Safety Switches, Available online: http://www.mechancontrols.co.uk/magnasafe_intro.asp, 2013.
7. Eureka, Informed Project Details, Available online: http://www.eurekanetwork.org/project/-/id/6748, 2011.