Institution: Liverpool John Moores University (LJMU)		
Unit of Assessment: UOA13		
Title of case study: Novel, non-destructive testing sensor platform for characterisation of insecticides and biohazards deposited on building materials		
Period when the underpinning research was undertaken: 2015-ongoing		
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 Patryk Kot Dr Magomed Muradov Prof Andy Shaw	Reader in Sensor Technologies Lecturer Professor in Microwave Technology	February 2016 – to present March 2017 – to present September 2005 – to present
Period when the claimed impact occurred: 2016 - to date		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

There are 200 million people at risk of visceral leishmaniasis (VL) globally; 65 million live in India and the majority of them in the State of Bihar. VL is fatal, if left untreated Malaria is endemic in >30 countries and 200,000 children die from the disease annually. The VL and malaria parasites are transmitted through infected female insect bites which require a bloodmeal to reproduce. VL and malaria control are by a World Health Organisation (WHO) recommended insecticide Indoor Residual Spraying (IRS) programme. Quality assurance of the spraying is essential for effective disease control. We have developed and operationally validated a self-contained sensor platform for IRS quality assurance, with orders in place for deployment in India. We are now extending this for the IRS market in malaria endemic countries globally. The technology was developed in collaboration with the Liverpool School of Tropical Medicine (LSTM) and funded by the Bill and Melinda Gates Foundation (BMGF). The sensor is used by the IRS programme in India to improve the local communities' quality of life by reducing the incidences of diseases in remote locations, where medical assistance is not readily available. The prototype has been field tested in different housing types in villages in Bihar state, India and proven successful; the patent has been filed for UK and US. This research led to extended product development with funding from Defence and Security Accelerator (DASA) (£150,000 - 6 months) and BMGF (£1,012,400 total value, £456,000 to LJMU over 3 years) to explore sensing of biohazards and neglected diseases.

2. Underpinning research

Our sensor platform has resulted in new diagnostic tools, with products adopted for use in a number of sectors including public health, building material characterisation and defence. LJMU has secured £1.5 million of R& D funding for the development of the electromagnetic sensor platform within the Built Environment and Sustainable Technologies (BEST) Research Institute.

The novel portable sensor technology has derived from initial underpinning research to identify the non-destructive and real-time detection of waterproof membrane failures in flat concrete roof structures mainly used in developing countries such as Malaysia and India. This technology allows the instant localisation of faults for spot repairs, preventing expensive refurbishment costs of entire roof structures. The initial work was funded by the University of Malaya, £11k (EF1),(CS2). The unique research outputs were demonstrated in (UR5) and (UR6). The knowledge gained during this research, namely, an understanding of working principle and interaction between electromagnetic spectroscopy and various properties/substances in building materials was a baseline for the development of the EM sensor platform. Additional research works were conducted to evolve the sensor platform, to study the influence of different anomalies (cracking formation, excess of the moisture) on EM spectroscopy in concrete structures (UR2) (UR3). This eliminated false sensor readings from non-uniform characteristic of measured materials, e.g. the reflection of the sensor signal is affected by various anomalies in building structures (cracks, moisture, chloride level, surface etc.). The outcomes of these research projects stimulated a new partnership with the Liverpool School of Tropical Medicine (LSTM), 2016. We developed a unique hand held prototype for quality assurance of alpha cypermethrin Indoor Residual Spraying (IRS) in India to monitor the level of insecticides deposited on the internal walls of houses made from various building materials (mud, thatch, brick, limewash etc.) in India. The funding originated from BMGF secured by LSTM in 2010 (CS1).

The Indian Government are now validating the portable self-contained sensor (UR4). The prototype has been field tested in over 50 houses in different villages in Bihar state, India. The results demonstrated that EM technology can be used to monitor the insecticide level on different building materials. The developed technology is under patent filing (PT1) before involving a commercial partner to manufacture the final device meeting the required regulations in India. We are now expanding the use of the sensor in Africa and investigate a wider range of insecticides funded by Bill & Melinda Gates foundation (EF7).

The partnership with LSTM has led to setting up a new sensor laboratory focusing on tropical neglected diseases in 2020, (LJMU funding £420k), based in Liverpool (EF6) as a part of a successful UKRI Strength In Places submission for £114million with 20 partners to deliver integrated therapeutic solutions for human infections.

The knowhow and understanding of EM interaction with composites on various building surfaces (UR4) allowed expanding research activities into a new sector, defence. Further funding was acquired from Defence and Security Accelerator (DASA) to develop a non-destructive sensor for the detection of biological hazardous materials – Phase I (UR1)(EF5). The proposed sensor creates a portable technique for non-invasive rapid measurements of hazardous biological material on different surfaces using Electromagnetic Spectroscopy. This sensor can be used as a portable device or implemented into any ground vehicles.

3. References to the research

The references to the research are demonstrated in this section. The acronyms used are as follow:

UR - Underpinning research output; **EF** - External funding; **PT** – Patent

The presented underpinning research outputs have been through a rigorous peer-review process by the world leading experts in the field for the high quality of the publication.

UR1. **Teng K**, **Idowu I**, **Kot P**, **Shaw A**, **Muradov M**. “Non-destructive Electromagnetic Wave Sensor for Hazardous Biological Materials” 12th International Conference on the Developments in eSystems Engineering (DESE2019) :1-6, 2019

UR2. **Gkantou M**, **Muradov M**, **Kamaris G**, **Hashim K**, **Atherton W**, **Kot P**. “Novel Electromagnetic Sensors Embedded in Reinforced Concrete Beams for Crack Detection,” Sensors, 19, pp. 1-14, 2019

UR3. **K. H. Teng**, **P. Kot**, **M. Muradov**, **A. Shaw**, **K. Hashim**, **M. Gkantou**, and **A. Al-Shamma’a**, “Embedded Smart Antenna for Non-destructive Testing and Evaluation (NDT&E) of Moisture Content and Deterioration in Concrete,” Sensors, vol. 19, pp. 1-12, 2019

UR4. **Kot P.**, **Muradov M.**, **Ryecroft S.**, **Ortoneda Pedrola M.**, **Shaw A.**, Hemingway J., Deb R., Coleman M., “Identification of Optimal Frequencies to Determine Alpha-Cypermethrin using Machine Learning Feature Selection Techniques" in IEEE Congress on Evolutionary Computation (IEEE CEC 2018), 2018

UR5. **P. Kot**, **A. Shaw**, **M. Riley**, A. S. Ali, and **A. Cotgrave**, "The Feasibility of Using Electromagnetic Waves in Determining Membrane Failure Through Concrete," International Journal of Civil Engineering, vol. 15, no. 2, pp. 355–362, 2017.

UR6. **P. Kot**, A. S. Ali, **A. Shaw**, **M. Riley**, and A. Alias, "The application of electromagnetic waves in monitoring water infiltration on concrete flat roof: The case of Malaysia," Construction and Building Materials, vol. 122, pp. 435–445, 2016.

EF1. Prof Mike Riley, Prof Andy Shaw, "The feasibility of using electromagnetic waves in determining membrane failure through concrete" University of Malaya, 2016, £11k

EF2. Dr Patryk Kot, Prof Andy Shaw, "Proof of concept sensor for the detection of alpha-cypermethrin on walls- Phase 1", BMGF, 2017-2017, £25k

EF3. Dr Patryk Kot, Prof Andy Shaw, "Proof of concept sensor for the detection of alpha-cypermethrin on walls- Phase 2", BMGF, 2018-2018, £100k

EF4. Dr Patryk Kot, Prof Andy Shaw, "Proof of concept sensor for the detection of alpha-cypermethrin on walls- Phase 3", BMGF, 2019-2019, £150k

EF5. Dr Patryk Kot, Prof Andy Shaw, "Novel Electromagnetic sensor for a non-destructive rapid detection of hazardous biological material, Phase 1",DASA, £150k

EF6. Dr Patryk Kot, Prof Andy Shaw and Dr Magomed Muradov, "Non-Invasive Diagnostics Platform", UKRI, Strength in Places Fund, for LJMU £420k, Total Grant value £114 million

EF7. Dr Patryk Kot, Prof Andy Shaw and Dr Magomed Muradov, "Insecticide Detector System for Field Use", BMGF, for LJMU £570k, Total Grant value £1 million

PT1. Insecticide sensor- GB1906691.9- Patent pending

PT2. A sensor for identifying the presence of a biological material in a sample- GB1916716.2- Patent pending

4. Details of the impact

Indoor residual spraying (IRS) remains a critical tool in reducing the global burden of malaria in endemic countries. Recent studies in different epidemiological settings have all shown that IRS has substantially reduced infant and child mortality from around 2 Million to around 200,000 deaths per year. It functions primarily by killing endophagous mosquitoes when they land on sprayed surfaces, as well as by deterring feeding mosquitoes from entering the house completely. On the other hand, it has been highlighted that the IRS spraying is not done particularly well as there is often under dosing. The current WHO recommendation for Quality Assurance is to use live insect bioassays on sprayed walls – this is impractical and never done, so there is no real Quality Assurance. Early attempts at biochemical tests had some success, but are relatively complex for field teams to undertake, so uptake has been limited. The LJMU sensor technology allows Quality Assurance to be put in place in a format that is relevant for use by the field teams and gives immediate read out of data, so that remedial action can be taken to improve IRS.

The diseases are currently controlled via indoor residual spraying (IRS), (CS1). Indian government (public health authorities) have around 2000 teams who are regularly sent to villages to apply insecticide to the walls inside houses. The amount of spray applied by these teams is critical to eradication of the diseases. Too little spray will leave insecticides behind, too much spray can cause health problems. According to Coleman et al (2015), the IRS programme in India was failing as it was poorly quality assured. Therefore, immediate action was required from Indian government. The Quality Assurance was performed by LSTM team in eight VL endemic districts in Bihar State, India, in 2014 and results demonstrated that 84.9% of walls were under-sprayed, 7.4% were sprayed in range, and 7.6% were over-sprayed. Given the poor quality of the DDT-based IRS owing to sand flies being resistant to DDT, the alpha-cypermethrin was introduced. This led to policy changes as the visual QA detection of insecticide was no longer possible as alpha cypermethrin do not leave a visible residue after spraying. Since the switch to the alpha cypermethrin, the Indian Government annual reports stated that the VL was falling for the first time ever in India and they have started the validation process with the WHO for VL elimination as a Public Health Problem, anticipating by 2021 they would be in this position – COVID has stopped the last two rounds of IRS and this is now likely to be pushed back a couple of years. Since the start of the sensor testing and validation in India, collected data from our trials and comparing with gold standard HPLC lab analysis have dramatically improved spray quality in India. The impact has occurred on people lives namely the VL transmission was reduced and no deaths occurred from VL since 2019.

At present, assessing the quality assurance of how much spray has been applied is complicated. It requires sophisticated laboratory equipment to test the dosage deposited on building walls. This method is expensive usually £5-10 per sample, time consuming (a typical run takes between 10 to 60 minutes) and impractical during field studies as it has to be operated in a laboratory environment, which are based long distance from remote villages, as each testing process typically takes 2 weeks.

LJMU’s technology provides an alternate quality assurance methodology which is cheap and in-situ. The sensors are hand-held and only take 30 seconds for measurement. A typical sensor costs as a one off is approximately £200.

LJMU has conducted trials in the field in over 50 houses with over 10,000 measurements taken in different villages located within Bihar state, India. In total, three field studies took place during different seasons (wet and dry seasons) for a duration of two weeks for each trial between 2016 and 2019. The sensor platform was also verified on various construction materials to demonstrate results’ consistency. These trials convinced the Indian government to support their quality assurance approach with this sensor technology, which enables supervisors to verify the spraying regime and correct the dosage of insecticide deposited on the wall.

As a result, the technology is going in to manufacture to produce 300 sensors in the first batch in 2021. It has been agreed with BMGF that this will be completed by a joint LJMU/LSTM SME with a target of setting up the company as a part of Strength in Places funding (EF6)(CS1). The COVID crisis has severely disrupted the pipeline of the manufacture and dispatch to Indian government, though ironically, new versions of this technology can potentially be developed to test for COVID residues.

Bill and Melinda Gates foundation have embraced this approach and would now like to broaden the research scope to other developing countries (Africa) and investigate other types of insecticides (EF7).

This technology has also attracted the attention of the defence industry. Current techniques used to determine the biological hazardous material require laboratory equipment and are not portable. LJMU’s technology (PT2) enables real-time data collection and instant decision-making to detect hazardous materials during operations in the field. DSTL team have successfully tested LJMU’s sensors in the laboratory environment detecting the presence of biological hazardous materials namely wood, glass, metal and plastic.

5. Sources to corroborate the impact

CS1. Director, Liverpool School of Tropical Medicine can confirm the impact generated by research and developed technology in the quality assurance field in public health sector

CS2. Deputy Dean of the Faculty of Built Environment University of Malaya can confirm the generated impact by research and sensor development for detection of waterproof membrane failure in concrete flat roof structures.