Institution: University of Hertfordshire

Unit of Assessment: 12 – Engineering

Title of case study: Novel biodetection technologies: protecting armed forces and civilians from biological attacks, strengthening crop protection and delivering economic impact.

Period when the underpinning research was undertaken: 2008 – 2019

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:
Daniel McCluskey	Associate Professor (Research)	2009 – present
Mark Tracey	Professor of Microtechnology	1993 – 2019
Ian Johnston	Associate Professor (Research)	2002 – present
Loic Coudron	Reader in Digital Microfluidics	2011 – present
Christabel Tan	Senior Research Fellow	2002 – present

Period when the claimed impact occurred: 2014 – 31 December 2020

Is this case study continued from a case study submitted in 2014? N

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

Based on fundamental research into engineered microfluidic systems the Centre for Research in Biodetection Technologies (CRBT) at the University of Hertfordshire (UH) has worked with government and industry to design, develop and optimise novel biodetection systems that detect, collect and analyse airborne toxins, bacteria and viruses. These technologies have delivered a '*significant leap*' in the UK Government's capability to defend armed forces and civilians against biological attacks. CRBT research underpinned both the design and evaluation of the award-winning Biological Surveillance and Collector System, delivered by an industry consortium led by Thales Group. It was signed into service for use by the Royal Air Force to protect British troops overseas and adapted into an export product for use in public venues for civilian protection. This contract, involving 26 companies, [TEXT REDACTED FOR PUBLICATION]. CRBT applied similar microfluidics principles to food security, working with industry to develop and commercialise a unique early warning system that identifies crop disease. The capabilities of the SporeSentry system have been made compatible with Fera Science's CropMonitor Pro platform, run by the Crop Health And Protection (CHAP) centre which provides real-time data on disease prevalence to farmers and growers in the UK. The data gathered by CropMonitor Pro also feeds into the National Reference Collection.

2. Underpinning research (indicative maximum 500 words)

For high-risk scenarios requiring early warning, such as biowarfare detection or disease monitoring, the ultimate goal is highly sensitive, real-time, *in situ* biological analysis. But the ability to deliver near-instantaneous information has long been constrained by hardware limitations associated with the time required to capture, process and assess biological targets. This is a particular problem in challenging military environments where speed is of the essence in order to maintain operational tempo and take decisions to limit the number of casualties and fatalities. Multidisciplinary research within CRBT has combined expertise in microfluidics, sample processing and handling, airborne collection and detection technologies, and integrated system design to engineer hardware capable of providing repeatable, reliable and rapid biological identification.

Microfluidics is the study of miniaturised devices that can manipulate and control the flow of very small volumes of fluid using engineered channels often measuring hundredths of a millimetre. Addressing both engineering and microbiological challenges, CRBT studies have shaped the development of novel microfluidic devices and their integration into portable, autonomous systems that can collect airborne particles, process them into liquids at the microscale and identify the presence of harmful pathogens. This work began in the early 2000s when a group led by Tracey studied real-time image processing of red blood cells flowing through the group's own designed silicon-glass microfluidic devices. The researchers extracted biophysical data for analysis and demonstrated reliable measurements of thousands of blood cells in cross-section channels measuring around three micrometres. This provided new insight into how microfluidic

components could be integrated into novel diagnostic instruments and designed to handle biological cells without damaging them. It led to the development of Micro Throttle Pumps capable of pumping undiluted, anticoagulated human venous blood; micropumping of whole blood represents a rigorous real-world test of cell suspension transport given blood's high cell content and the relative fragility of red blood cells [**3.1**].

These studies provided the theoretical underpinnings for a number of subsequent projects funded by Defence Science and Technology Laboratory (Dstl) to develop proof-of-principle microfluidics systems for operational use in relation to the detection of biowarfare agents. [TEXT REDACTED FOR PUBLICATION] [**G1**]. The CRBT group demonstrated the efficacy of microfluidic structures in the rapid, selective separation of microparticles from larger samples in order to detect pathogenic microorganisms [**3.2**]. They also provided new insights into the mechanical properties of a polydimethylsiloxane elastomer commonly used for fabricating microfluidic devices [**3.3**].

[TEXT REDACTED FOR PUBLICATION] Dstl sought to develop a wearable personal sampler system that could provide the military with a wider area biological monitoring capability, supplying information on who has been infected, what they have been infected with and their level of exposure. A key research challenge lay in ensuring the concentration of the liquid sample presented to the sensor was sufficiently high for detection, which required the system to produce a small output liquid volume. Under a four-year framework agreement worth £1.42m to UH [**G2**], a CRBT-Dstl collaboration developed a prototype digital microfluidics (DMF) platform based on an electrowetting-on-dielectric (EWOD) approach and electrostatic precipitation; it was capable of recovering target material and producing microlitre highly concentrated droplet samples [**3.4**]. The CRBT group identified the effectiveness of a superhydrophobic material as the coating for the actuation surfaces in the EWOD-based DMF devices; it was found to reduce the common issue of 'biofouling' (contamination) of the actuation surface [**3.5**].

Concurrently, the CRBT researchers applied these fundamental microfluidics principles to the field of food security; specifically, the development of a unique early warning system that could detect airborne fungal pathogens in cereal crops. Through £250,000 in funding from BBSRC and Innovate UK [**G3**], the group, in collaboration with commercial partners, led the development of the underpinning technology for the first autonomous spore-sampling system, intended for use by farmers and growers. At the end of both grants [**G2**, **G3**], the CRBT group published its bespoke DMF immunoassay platform that demonstrated, for the first time on an EWOD chip, rapid, efficient and specific detection of four types of pathogen – proteins, vegetative bacteria, bacterial spores and viruses [**3.6**]. This demonstrated its applicability to both biowarfare and crop disease detection.

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

3.1 Davies MJ, Johnston ID, Tan CKL, Tracey MC. Whole blood pumping with a microthrottle pump. Biomicrofluidics. 2010;4(4). 044112. https://doi.org/bp9r9s
3.2 Johnston I, McDonnell MB, Tan C, McCluskey D, Davies M, Tracey MC. Dean flow focusing and separation of small microspheres within a narrow size range. Microfluidics and Nanofluidics. 2014 Sep 1;17(3):509-518. https://doi.org/f6fnp2
3.3 Johnston I, McCluskey D, Tan C, Tracey MC. Mechanical Characterisation of Bulk Sylgard 184 for Microfluidics and Microengineering. Journal of Micromechanics and Microengineering. 2014 Feb 28;24(3). 035017. https://doi.org/ggv6wc
3.4 Foat TG, Sellors WJ, Walker MD, Rachwal PA, Jones JW, Despeyroux DD et al. A prototype personal aerosol sampler based on electrostatic precipitation and electrowetting-on-dielectric actuation of droplets. Journal of Aerosol Science. 2016 May 1;95:43-53. https://doi.org/f8d3jh
3.5 Abdul Latip EN, Coudron L, McDonnell MB, Johnston I, McCluskey D, Day R et al. Protein droplet actuation on superhydrophobic surfaces: A new approach toward anti-biofouling electrowetting systems. RSC Advances. 2017 Oct 25;7(78):49633 - 49648. https://doi.org/f96d
3.6 Coudron L, McDonnell MB, Munro I, McCluskey D, Johnston I, Tan C et al. Fully integrated digital microfluidics platform for automated immunoassay; a versatile tool for rapid, specific

detection of a wide range of pathogens. Biosensors & Bioelectronics. 2019 Mar 1;128:52-60. https://doi.org/ggqvwx

Key underpinning grants
G1 [TEXT REDACTED FOR PUBLICATION]
G2 Dstl (DSTL/AGR/00520/01). Research & Development for the detection & identification of Biological Warfare Agents. £1.42m. 2014 – 2018. PI: Tracey, then McCluskey.
G3 Innovate UK. Improved risk prediction for precision agriculture: automated monitoring of pathogen movement. £248,246. 2014 – 2018. PI: McCluskey

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

Microfluidic devices and systems developed at UH have had an impact in the fields of biowarfare, counter terrorism, and food security. CRBT research has made a fundamental contribution to the technological development of the next generation of biodetection systems, advancing the UK's defence capabilities. It led to the development and deployment of a novel biodetection system that is used by the Royal Air Force (RAF) to protect British troops overseas from biological attacks and that was adapted into an export product for civilian use; the production of this system was of significant benefit to the UK economy. The research underpinned the development of novel diagnostic device SporeSentry, which identifies pathogenic spores that can cause crop disease; the UK-wide CropMonitor Pro platform has been made compatible with SporeSentry.

Protecting UK armed forces overseas and civilians from biological attacks, enhancing the UK's defence capabilities and delivering economic impact

The UK's 2015 National Security Risk Assessment highlighted the risk of biological (and chemical) attacks against the UK or its armed forces, and the proliferation of chemical, biological, radiological and nuclear (CBRN) technology to state and non-state actors [**5.1**]. The development of biological detection systems that can be fielded by the UK armed forces is '*a high priority*' for the Ministry of Defence [**5.1**]. Based on several studies, including the collaborative microfluidics research with CRBT [**3.1**-**3.3**], Dstl's strategic approach to bio-surveillance led to the MOD issuing a commercial tender in 2014, for the development of a system that could rapidly detect the presence of hazardous aerosolised biological materials to protect military and civilian personnel [**5.2**]. CRBT research had an important role in shaping the technical specification of the call [**5.2**]. An industry consortium of 26 organisations, led by Thales Group and including Williams Advanced Engineering won the contract [**5.2**-**5.5**]. On the advice of Dstl, Thales approached UH, the only academic institution involved, to apply CRBT expertise, based on their published research and previous collaborations with Dstl, to the experimental work, engineering design and performance optimisation, and final evaluation [**5.2**, **5.3**].

The result was the Biological Surveillance and Collector System (BSCS), which comprised a number of pathogen collection platforms, and a sample processing and identification laboratory. BSCS was signed into service having achieved full operating capability in November 2017, to be operated by the RAF; the BSCS was highlighted as a key project in the 2018-2021 Corporate Plan for Defence Equipment and Support, which supports the UK's Strategic Command [**5.4**]. The RAF Air Commodore, who was responsible for the delivery of the system into service, said at the time: '*BSCS is a critical capability for our deployed forces in an uncertain world. Asymmetric Warfare has presented CBRN (chemical, biological, radiological and nuclear) challenges, the most recent of which being the chemical attacks in Syria - the biological threat to our forces is no less critical* [**5.5**].' The RAF Wing Commander overseeing the regiment that operates the BSCS said: '*The superb degree of confidence provided by BSCS is game changing and will allow commanders to take action in a timely manner to maximise the protection of our people* [**5.5**].'

The BSCS won a Minister for Defence Procurement Acquisition Award in November 2017. Harriet Baldwin MP, the Minister at the time, commented: "*The Biological Surveillance and Collector System (BSCS) is a cutting-edge piece of kit that uses innovative technology to protect our*

troops from biological attacks through using specialist sensors to detect incoming threats. In the last year we spent £18.7bn with industry to support programmes like this to keep our troops safe in some of the most hostile environments [**5.6**].' The BSCS was also adapted into an export product for civilian use. Called Spinnaker, it is designed to protect sporting events, critical national infrastructure and large-scale public gatherings. An article on the Thales website reported: '*Thales's Spinnaker has bio-monitoring capability, with a mobile laboratory to ensure fast analysis of potential threats*.' It said that such CBRN systems are '*proving invaluable in civilian scenarios and increasingly procured by Government departments for domestic security*' [**5.7**].

The development of the BSCS delivered significant benefits to the wider UK economy. [TEXT REDACTED FOR PUBLICATION] comprising a supply chain of 26 organisations, the majority of which were UK-based and 17 of which were SMEs [**5.3**]. [TEXT REDACTED FOR PUBLICATION]. Independent consultancy Oxford Economics, in its report '*The Contribution of Thales to the UK Economy*' (March 2019), highlighted BSCS as a case study to demonstrate the company's '*multiplier impacts*' and the fact that Thales '*enables partners to contribute to large contracts, in turn supporting further supply chain activity among their suppliers*' [**5.8**]. There were also reputational benefits for the companies involved. Thales was able to highlight the BSCS in its own marketing and PR campaigns, including the marking of the 100th anniversary of the RAF in July 2018 [**5.9**]. Williams Advanced Engineering cited the BSCS and the ministerial award in a case study of how it '*specialises in complex technological problem solving and bringing Formula One technology and processes to industry*' [**5.9**].

Dstl's decision to invest £1.42m in a research collaboration with UH between 2014 and 2018 [**G2**] was driven by the need to further advance state-of-the-art biodetection technologies that could increase the speed and efficiency of operations in the field [**5.1**]. The collaboration resulted in the development of two highly portable, compatible prototype systems: a wearable electrostatic precipitator system for collection of airborne biological material [**3.4, 3.5**] and a digital microfluidic platform for sample recovery and concentration of collected biological material [**3.6**]. Dstl reported that the technologies resulted in three patent applications, '*demonstrated their potential to be highly innovative'* in both military and civilian contexts and delivered '*a significant leap in capability'* in relation to biological surveillance [**5.1**].

Commercialisation of an early warning crop disease detection system to alert farmers and growers and strengthen food security

The idea to apply the fundamental research principles underlying the capture and analysis of germ warfare agents to the development of a disease risk prediction system for agriculture came from UH researchers, led by McCluskey. Funded by Innovate UK [**G3**], the CRBT group worked with Fera Science Ltd, Bayer Crop Science and UK SME Optisense Ltd to design SporeSentry, the first autonomous spore-sampling system than can detect airborne fungal pathogens in cereal crops, which cost the UK £120m annually. The technology, for which UH and Optisense jointly own the IP, comprises an air suction spore trap that takes in air and captures fungal spores. These are analysed, the data is merged with weather data, and a forecast disease risk is sent to farmers and growers via an online platform. The system is designed to allow more effective timing and targeting of fungicide control, saving farmers and growers money and giving them more time to tackle the disease, thus increasing yields and profitability. It also benefits the environment and addresses the growing problem of fungicide resistance.

In the development phase McCluskey showcased pre-production systems at Cereals 2017, 2018 and 2019 (Europe's leading technical event for the arable industry) and at the American Phytopathology Society annual meeting in Cleveland in August 2019. He worked with the British Embassy in Colombia so they could showcase the technology at Latin America's Expo Agrofuturo in 2018 and 2019. The system was well received by the sector. Bayer described Spore Sentry as '*one of the most exciting projects*' in disease forecasting as it can warn farmers of crop infections '*up to three weeks before they can see the disease, allowing much more time to tackle the pathogen*' [**5.10**]. One agronomist told Agronomist & Arable Farmer magazine [**5.11**]: '*My time on farm is precious so having an idea on potential issues in advance will allow*

me to manage my time more effectively … this technology will allow us to schedule sprayer patterns by crop risk. Farm revenue is ultimately down to optimising crop performance, knowing which fields are under the greatest risk is bound to benefit.' A *Farmers Weekly* article on '3 high-tech gadgets for monitoring crop diseases' highlighted Spore Sentry as '*the most interesting technology*' of the three [**5.11**].

In September 2020, Fera Science and Crop Health and Protection (CHAP) launched CropMonitor Pro, a digital decision support system that helps farmers, growers and agronomists predict the likelihood of pest and disease outbreaks for winter wheat, winter oilseed rape and potatoes at field level. It was funded by Innovate UK as part of the UK Government's Agri-tech strategy and is available on a subscription basis. The platform has been '*designed to facilitate incorporation of as many automated solutions as possible to improve accuracy and reduce overhead costs*' [**5.12**]. This includes '*a new automated spore collection and diagnosis device (SporeSentry) which will communicate detection of pathogen spores to the CropMonitor Pro platform to enhance model outputs*' [**5.12**]. Pre-production prototypes of the SporeSentry are available for use by Fera Science and the CropMonitor programme. Full production of the SporeSentry was due to commence in Q1 2020 but halted due to the strategic decision by Optisense to support the national Covid response through increased production and support of Molecular Diagnostic platforms for the detection and analysis of SARS-CoV-2. Production resumed in 2021 with units ready for market in 2022 [**5.13**].

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

5.1 [TEXT REDACTED FOR PUBLICATION]
5.2 [TEXT REDACTED FOR PUBLICATION]
5.3 [TEXT REDACTED FOR PUBLICATION]
5.4 Defence Equipment and Support, Corporate Plan: 2018-2021. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/707889/DES-Corporate-Plan-2018-HighRes.pdf (page 22)
5.5 Article on Thales Group website: *Thales Biological Surveillance and Collector Systems*. https://www.thalesgroup.com/en/united-kingdom/news/thales-biological-surveillance-and-collector-systems
5.6 Article on Thales Group website: Protecting UK armed forces from threat of biological attack. https://www.thalesgroup.com/en/united-kingdom/news/protecting-uk-armed-forces-threat-biological-attack
5.7 Article on Thales Group website: Secure communications and protection systems. https://www.thalesgroup.com/en/countries/europe/united-kingdom/markets-we-operate/security-uk/secure-communications-and-protection-systems
5.8 Oxford Economics: The contribution of Thales to the UK economy, March 2019 (PDF, p.25).
5.9 Case study articles on Thales Group and Williams Engineering websites: https://www.thalesgroup.com/en/europe/united-kingdom/our-commitment-uk/trusted-partner/thales-and-raf100; https://www.williamsf1.com/advanced-engineering/news/2017/12/williams-advanced-engineering-and-thales-collaboration-awarded-defence-industry-accolade
5.10 Article on Bayer Crop Science website: Smarter ways to forecast crop disease. https://cropscience.bayer.co.uk/blog/articles/2017/03/smarter-ways-to-forecast-crop-disease/
5.11 Selected media coverage of the SporeSentry device. http://www.aafarmer.co.uk/crops/spore-trapping-technology-on-show-at-open-day.html https://www.fwi.co.uk/arable/crop-management/disease-management/3-high-tech-gadgets-for-monitoring-crop-diseases
5.12 Article on Fera Science website about the CropMonitor Pro service (including SporeSentry). https://secure.fera.defra.gov.uk/cropmonitor/smart.cfm
5.13 Letter from Managing Director, Optisense, confirming disruption of COVID-19 pandemic.