Institution: University of Chichester

Unit of Assessment: UoA 12 (General Engineering)

Title of case study: Commercial Applications for Microwave and Millimetre-wave Sensing: Security, Non-Destructive Evaluation and Health

Period when the underpinning research was undertaken: 01/01/2014-31/12/2020

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:
Professor Stuart Harmer	Head of Department of Engineering & Design	June 2016-present
Dr Hashim Bhabba	Senior Lecturer in Mechanical Engineering	June 2018-present

Period when the claimed impact occurred: November 2018-present

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

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

University of Chichester (UoC) research has shown how microwave and millimetre-wave sensing can significantly improve a wide range of security screening processes (most notably the screening of air passenger footwear), and provide important innovations in various waste recycling and healthcare contexts. These findings have resulted in 2 patents and the formation of a publicly listed company (PLC) that has so far raised over USD3,500,000 in private sector investment to develop this research into commercially viable products. UoC security screening technology has also been selected for trial by the US Department of Homeland Security.

2. Underpinning research (indicative maximum 500 words)

Microwave and millimetre-wave sensing is often used in airport security due to its application in body scanner technology. The reason for this is that the penetration of electromagnetic radiation at these frequencies is simultaneously highly effective (e.g., through clothing), and, unlike x-rays, poses no health-related risks. Current body scanning systems, however, remain unable to screen the soles of shoes, and thus typically necessitate the removal of footwear, which significantly reduces 'throughput' (scanning speeds) and user convenience. As a consequence of these limitations, and others related to the cumbersome and costly equipment these techniques typically require, microwave and millimetre-wave technology is under-explored in many other contexts requiring non-destructive evaluation (NDE) capabilities, such as waste recycling and healthcare.

Addressing this problem, UoC researchers have conducted significant research into the utility of microwave and millimetre-wave sensing for a wide variety of security screening and threat detection capabilities [**R1, R2**]. This has included establishing the viability of microwave and millimetre-wave scanning for assessing bodily wounds without requiring that they first be undressed [**R3**, **R4**], assessing the structural integrity of concrete buildings, and rapidly classifying and sorting waste types in automated recycling plants [**R5**]. The deployment of millimetre-wave imaging systems for large area NDE applications (such as building inspections) are currently limited both by system costs (amounting to c. GBP50,000 per sensor) and weight (typically 20kg per sensor). In response to this, Stuart Harmer has also contributed towards a project developing planar diffraction antenna technology, establishing that it permits a significant size, weight and cost reduction over conventional quasi-optical millimetre-wave imaging systems

[**R6**]. Taken together, this body of research establishes for the first time the potentially transformative applications of microwave and millimetre-wave sensing in a wide range of industries.

Addressing the problem of shoe removal in airport security, the UoC researchers have developed the first ever security scanner that can identify metal and non-metal materials concealed in the soles of shoes, to an accuracy level that satisfies all international airport security specifications. The intellectual property associated with this technology has been subject to 2 patents [including **R7**] to protect its commercial prospects, both of which have been assigned to a new publicly listed company, Plymouth Rock Technologies (formed in 2018).

The opening up of new applications for microwave and millimetre-wave technology will assist in driving the cost reduction of key components (e.g., low noise amplifiers, mixers and detectors) by providing an additional market into which these devices can be sold, and will thus provide benefits to areas which currently have no practicable or sub-optimal solutions.

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

[**R1**] Book – published
Boris Y. Kapilevich, **Stuart Harmer**, Nicholas J. Bowring: Non-Imaging Microwave and Millimetre-Wave Sensors for Concealed Object Detection. March, 2017; CRC Press., ISBN 9781138072749.

[**R2**] Journal Paper – published
Stuart Harmer, Christopher I. Johnson, Dana E. Wheeler, and **Hashim Bhabha**, "Thermography at Millimetre Wavelengths for Security Inspection of Footwear," Progress In Electromagnetics Research M, Vol. 88, 83-89, 2020. doi:10.2528/PIERM19100602.

[**R3**] Journal Paper – published
Stuart Harmer, Sergiy Shylo, Mamta Shah, Nicholas John Bowring, Amani Yousef Owda: On the feasibility of assessing burn wound healing without removal of dressings using radiometric millimetre-wave sensing. Progress In Electromagnetics Research M 01/2016; 45. DOI:10.2528/PIERM15110503.

[**R4**] Journal Paper – published
Amani Yousef Owda, Neil Salmon, **Stuart Harmer**, Sergiy Shylo, Nicholas John Bowring, Nacer Ddine Rezgui, Mamta Shah: Millimeter-wave emissivity as a metric for the non-contact diagnosis of human skin conditions: Bioelectromagnetics. Volume 38, Issue 7 October 2017 Pages 559–569. DOI: 10.1002/bem.22074.

[**R5**] Journal Paper – published
Sergey Shylo, **Stuart Harmer**: Millimeter-Wave Imaging for Recycled Paper Classification. IEEE Sensors Journal 01/2016; 16(8). DOI:10.1109/JSEN.2015.2512106.

[**R6**] Conference Proceeding – published
Stuart Harmer, Sergiy Shylo , Yuriy Sydorenko, Dana Wheeler , Douglas Dundonald, “Passive Millimetre-wave Imaging with a Planar Diffraction Antenna,” 2014 9th International Symposium on Communication Systems, Networks & Digital Sign (CSNDSP).

[**R7**] PATENT – filed, pending.
US 16/560,480 “Method and System for Determining the Dielectric properties of an Object,” **Stuart Harmer**, Dana E. Wheeler. Filing Date 04/09/2019.

All outputs available on request.

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

Developing new technologies from 'proof of concept' and through to a higher 'technology readiness level' (TRL) is time-consuming, expensive, and often well beyond the scope of most university-based research activities. In order to realise significant impacts from research outputs, proof of concept devices and intellectual property, investment and commercial interest is nearly always required. Research can thus provide deployable solutions to real-world problems.

In order to facilitate the development of UoC microwave and millimetre-wave research on a large scale, Harmer set up Plymouth Rock Technologies in 2018, to attract the private capital needed to develop it into commercially viable and deployable solutions. By late 2018, Plymouth Rock Technologies was trading on the Canadian, US, French and German stock markets, providing the business structure, investment and commercial awareness required to commercialise the UoC's innovative security screening and NDE technology.

As a result of this, Plymouth Rock Technologies now employs 10 people on a full-time basis, contributing over USD1,000,000 annually into the US and UK economies through staff salaries and sustaining a supply chain worth over USD10,000 per month. To date, Plymouth Rock Technologies has attracted private investment amounting to over USD3,500,000, and achieved a market capitalisation of roughly USD70,000,000. This investment is now being used to develop 'beta' versions of the UoC's microwave/millimetre-wave security scanners and a drone platform designed to carry them for large-scale scanning applications [**C1**].

Security screening

In November 2020 the UoC's footwear scanner was selected by the US Department of Homeland Security (DHS) to undergo demonstration trials as part of their remit to provide safer air travel and mitigate security staff risks associated with the COVID-19 pandemic. In response to the COVID-19, the DHS has been seeking technologies that will permit security staff remotely to screen air passengers whilst maintaining social distancing between themselves and those passengers.

The DHS requires that the technology be at a 'technology readiness level' (TRL) of 6, which has only been possible due to the resources provided by Plymouth Rock Technologies in bringing the UoC's research and proof of concept to a deployable level. If successful, these trials will permit the DHS to purchase and deploy shoe scanning devices for use in US airports [**C2**]. Security screening represents a c. USD9,000,000,000 annual market [**C3**].

NDE inspection of from small drone (UAV) platforms

To date, the inspection of large structures, such as buildings, ships, bridges and petrochemical plants and pipelines has typically been carried out by eye, which is both expensive and slow, and frequently exposes inspectors to health risks. In some cases, plants must be shut down during these inspections, making them very costly and inconvenient. The rapid growth of the development of unmanned aerial systems (drones), however, provides an ideal, comparatively inexpensive and flexible platform from which NDE can be carried out. Plymouth Rock Technologies is currently testing millimetre-wave sensors from their 'X1' drone platform, and gathering information on the capability that this offers in the inspection of large structures [**C4**]. Thermal imaging (thermography) is a c. USD10,000,000,000 annual market with c. 8% compound annual growth rate [**C5**].

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

[**C1**] Testimonial statement from Mr Dana E. Wheeler (CEO, Plymouth Rock Technologies), assignee of research generated IP and commercialising footwear security screening and drone-based NDT technology.

[**C2**] Letter of confirmation from the US Department of Homeland Security/TSA.

[**C3**] 'Security Screening Market by Product (X-Ray & Biometric Screening System, EDT, and Metal Detector), By Application (Airport, Government, Border Security, Education, And Private & Public Places), And by Geography – Analysis and Forecast to 2013 – 2020', *Markets and Markets* (September 2014): https://www.marketsandmarkets.com/Market-Reports/security-screening-market-264685413.html.

[**C4**] Mr Carl Cagliarini (Chief strategy officier PRT)

[**C5**] 'NDT and Inspection Market with COVID-19 Impact by Technique (Visual Testing, Magnetic Particle, Liquid Penetrant, Eddy-Current, Ultrasonic, Radiographic, Acoustic Emission), Method, Service, Vertical, and Region – Global Forecast to 2025', *Markets and Markets* (November 2020): https://www.marketsandmarkets.com/Market-Reports/non-destructive-testing-ndt-equipment-services-market-882.html?gclid=Cj0KCQjwuZDtBRDvARIsAPXFx3ABKAS2_cS2QQEYw6bJMBHyb95EfzCmZVPe-recPKiXUtVsrSWI4tgaApXdEALw_wcB.