Institution: University of Huddersfield		
Unit of Assessment: UoA 12 Engineering		
Title of case study: Enabling Worldwide Industry Innovation through the Development of Surface Characterisation and their Standardisation		
Period when the underpinning research was undertaken: 2000-2012		
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:**
Prof Liam Blunt	Chair of Surface Metrology	1997 - present
Prof Xiangqian (Jane) Jiang	Chair of Precision Metrology	1997 - present
Prof Paul Scott*	Taylor Hobson Chair * 1997- 2010: 2 days /per week, Secondment from Industry	2010 - present
Period when the claimed impact occurred: 2014 - 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Research in surface metrology at Huddersfield has impacted on the global manufacturing industry through international standardisation of areal (3D) surface characterisation (ISO 25178 part 2, 3, and 71). These enabled the consistent interpretation of surface data and aided cooperation across industrial supply chains for many manufactured components worldwide. Today, products from all surface metrology instrument manufacturers are compliant with these ISO standards. A leading metrology software vendor, Digital Surf, has incorporated the research findings directly into its products and 80% of surface measurement instruments in industry globally use their software. The resulting interoperability has hugely benefited end-user companies and consumers by enabling instrument sales, speeding up new product and new applications development.

2. Underpinning research

Surface metrology is the science of measuring small-scale geometrical features (roughness) on surfaces - the surface topography. This is important because, for instance, the control of surface texture allows automobile engines to have reduced running-in times, operate more efficiently and emit reduced emissions. Similarly, orthopaedic implants last longer when their surface topography is optimised. Traditional surface measurement techniques were 2D (so-called profile) and relied on moving a stylus across the surface to be characterised. The topography was measured but only along the exact contact line. In the late 1990s, new quantitative 3D (so-called areal) techniques, such as optical interferometers and electron microscopies, were developed. These collected more detail with greater fidelity. However, each instrument manufacturer developed its own protocols to interpret the measurements and therefore results from different instruments were incompatible. This disrupted the adoption of the new areal techniques because the members of a supply chain could not communicate this new generation of surface measurement in a reproducible and consistent manner.

To resolve such chaos in industry, the representative underpinning research conducted by the Huddersfield team was as follows:

<u>A Surface Assessment Framework</u> was created to develop technologies for areal analytics under the EU SurfStand Project, with Liam Blunt as the PI/coordinator and with 3 academic and 7 industry partners. The framework included surface characterisation, instrumentation and a series of case studies in automotive production, sheet steel manufacture and orthopaedic implant manufacture [1].

A Set of "Field" Numerical Parameters were systemically developed based on statistics calculated from the surface, to classify: deviations, extremes and specific features from a scale-limited topography. As a result, a field surface parameter set was formulated, that were stable, reliable and had functional correlations, describing electrical, thermal, sealing and running-in wear properties (Chapter 2 of [1]).

Novel Segmentation methods were created to decompose a surface into stable features using pioneering fundamental mathematics [2], enabling the analysis of surface features and structures (attributes and their relationships), allowing new approaches to the analytics of surface function (lubrication, paintability, illumination and defects, etc.) in Chapter 3 of [1].

First Generation of Areal Filters were originated with the EU Surfstand project; and followed by two EPSRC Filtration Projects with Jane Jiang as PI, including Wavelet filtration allowing multi-functional surface analytics [3] and generic Gaussian filters from linear to non-linear with fast and robust algorithms [4]. These allowed the establishment of robust reference and residual surfaces at any scale (from micro to sub-nanometers) with fidelity for further parametric assessment, originally discussed in Chapters 5 and 9 of [1].

Application Technologies were explored (with refined and optimised algorithms) and applied to a wide range of surfaces, from automotive, bio-engineering to semiconductor sectors. These were tested and validated by the project partners in real industrial surface quantification scenarios. For example, Volvo undertook 'blind' engine tests, analysing the emissions performance of a series of engines and found excellent correlation between the emissions measured and those predicted by the parameter values. The findings were summarized in a series of case studies [1], which clearly showed that measuring and characterising surface texture in areal mode provided massive advantages in understanding surface functions such as wear, paintability, formability and bio-tribology.

This underpinning research received worldwide recognition. In January 2002, ISO/TC 213 invited the Huddersfield team to present their initial findings and technologies, leading to a surface texture taskforce being set-up in June 2002 (as recorded in ISO/TC213 *Resolution 483, Madrid, Spain). In 2003 a new Working Group WG16 was formulated to develop areal surface texture standards (ISO 25178 series, recorded in *Resolution 512, St Petersburg, USA), where *Paul Scott led the surface parameters standards and *Jane Jiang led the software measurement standards. The mathematical results of the research [1-4] were hard-coded into software tools and released as a bespoke non-commercial software package, "SURFSTAND". In 2007 and 2012, two papers [5-6] formalized the paradigm shift (both of scientific and technological aspects) that had taken place in surface metrology from profile to areal measurement. This research also resulted in the training of 8 PhDs and 2 Postdocs (3 females). Note: *Resolution 483 and *Resolution 512 see Page 1 & 2 [E1]; *Paul Scott and *Jane Jiang see Page 3 & 4 [E1]

3. References to the research

The following outputs provide reference to the body of research and are 2* or higher, being published in high quality peer-reviewed journal articles or well cited books.

[1]. Blunt, L., & Jiang, X. (2003). Advanced techniques for assessment surface topography: development of a basis for 3D surface texture standards "SURFSTAND". 355 pages, 1st edn, London Penton Press, Elsevier. ISBN 978-1-903996-11-9, 2003. https://www.sciencedirect.com/book/9781903996119/advanced-techniques-for-assessment-surface-topography (Cited 411). [can be supplied on request]

[2]. Scott, P. J. (2004). Pattern analysis and metrology: the extraction of stable features from observable measurements. Proceedings of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences, 460(2050), 2845-2864. DOI: https://doi.org/10.1098/rspa.2004.1291 (Cited 87). [can be supplied on request]

[3]. Jiang, X., & Blunt, L. (2004). Third generation wavelet for the extraction of morphological features from micro and nano scalar surfaces. Wear, 257(12), 1235-1240. DOI: https://doi.org/10.1016/j.wear.2004.06.006 (Cited 65).

[4]. Zeng, W., Jiang, X., & Scott, P. J. (2010). Fast algorithm of the robust Gaussian regression filter for areal surface analysis. Measurement Science and Technology, 21(5), 055108. DOI: https://doi.org/10.1088/0957-0233/21/5/055108 (Cited 47). [can be supplied on request]

[5]. Jiang, X., Scott, P. J., Whitehouse, D. J., & Blunt, L. (2007). Paradigm shifts in surface metrology. Part II. The current shift. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 463(2085), 2071-2099. DOI: https://doi.org/10.1098/rspa.2007.1873 (Cited 265).

[6]. Jiang, X. J., & Whitehouse, D. J. (2012). Technological shifts in surface metrology. CIRP annals – Manufacturing Technology, 61(2), 815-836. DOI: https://doi.org/10.1016/j.cirp.2012.05.009 (Cited 234).

*Note: In [5] and [6], *D.J. Whitehouse Emeritus Professor Warwick University, Visiting Professor University of Huddersfield 2005-present*

4. Details of the impact

Published Areal Surface Standards (ISO 25178 - Part 2, Part 3, Part-71)

Three parts of the standards on areal surface characterisation [ISO 25178 series] resulted from the research [1-6]. Two were drafted by Paul Scott and one on areal surface software standards was drafted by Jane Jiang: The Draft International Standards (DIS) were voted by country representatives by 18/18 (Part 2, *Doc N1015, 2008), 18/19 (Part 3, *Doc N1129, 2008) and 17/18 (Part 71, Doc *N1182, 2010) Countries; and the Final Draft International Standards (FDIS) were voted by country representatives by 21/21 (Part 2, *Doc 1368, 2011)), 19 /19 (Part 3, *Doc N1480,2011) and 18/18 (Part 71, *Doc N1539, 2012) Countries [E1]. As a result, ISO 25178-2 Geometrical Product Specification (GPS) – Surface Texture: Areal - Part 2: Terms, Definitions and Surface Texture Parameters (2012); Part 3: Operators (2012); and Part 71: Software measurement Standards (2012) were published by the International Organization for Standardization, Geneva [E2, E3].

The new standards were adopted from 2014 onwards by all OEM manufacturers of ISO compliant surface measurement equipment, influencing metrology across a wide range of manufacturing industries. The Lead Standards Development Manager at BSI wrote: “The work from the Huddersfield team has been fundamental in the wide acceptance of ISO standards worldwide and has facilitated the impact of the GPS standard ethos across wide swathes of manufacturing engineering” [E4]. Up to now, ISO 25178 Part 2 and Part 3 [E2] have had more than 4000 citations (Google Scholar). Based on the standards, interoperability was enabled along engineering supply chains that needed to share consistent surface metrology protocols. This accelerated, and lowered the cost of innovation, and resulted in commercial benefits for (i) businesses that provide measurement technology, (ii) companies that manufacture products that rely on consistency in surface functionality and (iii) consumers.
Note: *Doc N1015, *Doc N1129 and *Doc N1182 see Page 7,12, 17 of [E1]; *Doc N1368, *Doc N1480 and Doc *N1539 see Page 5,10,15 of [E1].

Commercial Impact for Suppliers of Metrology Instrumentation

During the course of the research and subsequent standards development, the Huddersfield team worked with leading suppliers of surface metrology instruments and software developers to ensure the outputs were industrially applicable. The ISO standard has superseded any proprietary software they may have developed historically.

Digital Surf

Digital Surf specialised in manufacturing 3D non-contact laser profilometers. From 2014 it began to use the output of the SURFSTAND project and the ISO standards to develop a surface analysis software package, MountainsMap®, and since then it has incorporated developing ISO standards into it. Today, Digital Surf's Mountains® software provides visualization, analysis and reporting tools for data output to a wide range of commercial profilometers and microscopes. Since 2016 the company has outsourced the development of many of its updated algorithms to the University of Huddersfield (UoH). Following the success of Digital Surf, many metrology instrument companies (including larger ones such as Bruker, Zeiss, Nikon and Taylor Hobson) no longer develop "in house" areal software but instead use the Mountains® package. It is now embedded in the equipment of the majority of profilometer (40+) and scanning probe / scanning electron microscope manufacturers (10) and it provides software for 80% of the world market in the field. MountainsMap® has an installed base of 12,000+ licenses worldwide and fully supports the ISO 25178 standards. The VP of Digital Surf confirmed, "The embedding of this research into our products, [..], was a key factor for the Company to develop market leadership and achieve an extremely diverse user-base worldwide, in the profilometry market. Digital Surf is doing around 4 million euros of sales per year, 75% of which is on the profilometry market, which is the main market concerned by ISO parameters and filtration" [E5].

Since 2017 the Huddersfield team has supported the development of new software modules for Digital Surf's next generation software, MountainsMap® 8. Since the release of the new software version in 2019, sales have gone well (licenses sold per annum (>1,200)). Digitalsurf's mid-range software retailed for approximately €15,000 in 2020 and the company estimated the increase in turnover to be €20M linked to the underpinning research. In 2019 Digital Surf developed a new version of MountainsMap® moving from a grid representation of surface to a triangular mesh (based on book produced at UoH ISBN 9780128218150 and papers, e.g. https://doi.org/10.1016/j.measurement.2017.05.028). This has opened new markets, such as in the area of x-ray computer tomography (https://doi.org/10.1016/j.precisioneng.2016.12.008). As a result Huddersfield has expanded its formal research contract with Digital Surf to develop new modules for MountainsMap® (MESHSURF) under the University of Huddersfield and Digitalsurf Agreements: Phase I (signed 20th December 2019) & Phase II (signed 11th November 2020). The Technical Director at Digital Surf stated, "We recognise Huddersfield's continued world-leading position in surface metrology research and the value that we as a business can gain from maintaining a close and mutually beneficial collaboration" [E5].

Bruker Alicona

Bruker Alicona provides optical industrial measurement technology for the quality assurance of complex components used in the automotive industry. Its core competence is the measurement of dimension and surface topography; this is based on focus variation. Since 2008 the company has developed its software to incorporate algorithms extracted from the ISO standards into its products. The Head of R&D said "around 15% of our customers use surface roughness with their instruments…a core element of our analysis capability within our software makes use of the research carried out by the Huddersfield team on areal roughness parameters" [E6].

Commercial Impact for Industry End-Users

The end users of the research output cover a wide range of industries. Examples are given below:

Volvo: used the research in its development of IC engines with reduced emissions. The Company Surface Engineering Specialist for Cylinder Liners stated, "in this area, the use of areal roughness parameters has been a core tool in understanding engine performance, engine wear and consequent emissions [..] we have now written their application into our company standards" [E7].

Sarclad: is the world's leading producer of Electrical Discharge Roll Texturing (EDT) machines, which are used in the automotive industry to make sheet metal easier to form and paint. The Head of R&D wrote, "Textured sheet metal using EDT is specified by all major automotive OEMs as a means of improving formability of sheet [..] the continued success of our Rolltex product range is helped significantly by the ISO 25178 areal surface measurement characterisation and the underpinning work of the Huddersfield team" [E8].

DePuy Synthes: is a world leading bio-implant manufacturer. Surface roughness is a key determinant of how successfully a surgical implant (e.g. replacement hip joint) bonds/integrates with the patient's bone and also the life of the joint bearing surfaces. The DePuy Testing Laboratory Manager commented, "Areal surface roughness parameters developed at [UoH] are of great importance to our industry and the development of new orthopaedic implants. [..]. The research conducted at the University of Huddersfield has helped shape ISO 25178 that is widely used in our industry" [E9].

Digital Metrology: has provided independent consultancy on surface metrology for over 30 years, mainly in the USA. Its President confirmed, "Without the underpinning work on parameters at Huddersfield, the field of areal surface metrology would have been significantly delayed and would certainly have been disparate and where adopted, would have been utilized within individual silos minimizing its impact and usefulness in innovation and international trade" [E10].

5. Sources to corroborate the impact

[E1]. ISO/TC 213 Resolutions regarding outcome of Huddersfield's underpinning research; set-up ISO/TC 213 working Group and different stage voting results for ISO 25178 Part 2, Part 3 and Part 71.

[E2]. ISO 25178 Geometrical Product Specification (GPS) - Surface Texture: Areal - Part 2: Terms, Definitions and Surface Texture Parameters (Page 1-54), and Part 3: Operators, International Organization for Standardization (Page 55-80), Geneva (2012)

[E3]. ISO 25178 Geometrical Product Specification (GPS) - Surface Texture: Areal - Part 71: Software measurement Standards, International Organization for Standardization, Geneva (2012)

[E4]. Letter from Lead Standards Development Manager, BSI, 25th March 2020.

[E5]. Letter from VP, Digitalsurf (Software Vendor), 17th April 2020

[E6]. Letter from Head of R&D, Alicona (Instrument Manufacturer), 22nd April 2020

[E7]. Volvo - Value of UoH-based ISO (End user - Automotive), 25th October 2020

[E8]. Sarclad - Value of UoH-based ISO (End user - Steel), 2nd November, 2020

[E9]. DePuy - Value of UoH-based ISO (End user - Bio Implants), 1st November 2020

[E10]. Michigan Metrology (USA Metrology Consultant and Stds Committee),16th December 2020