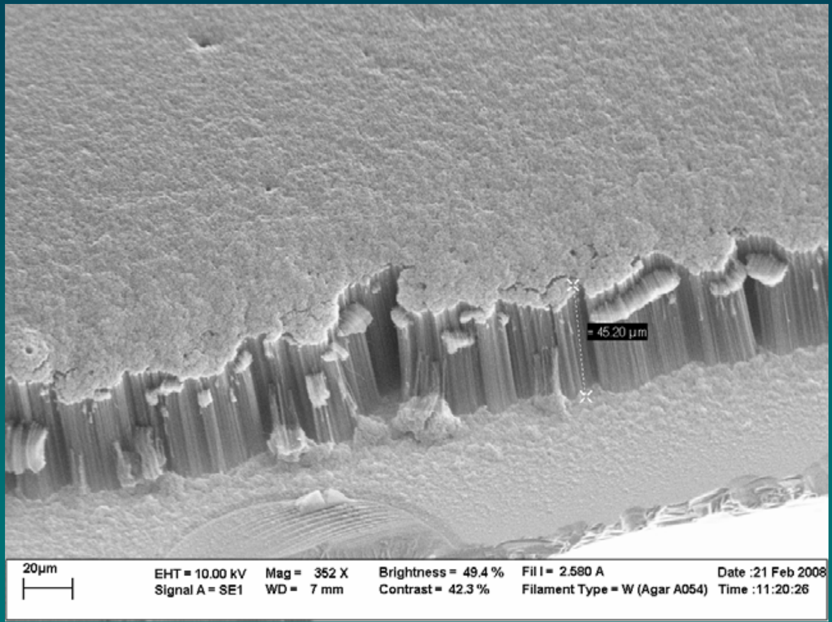
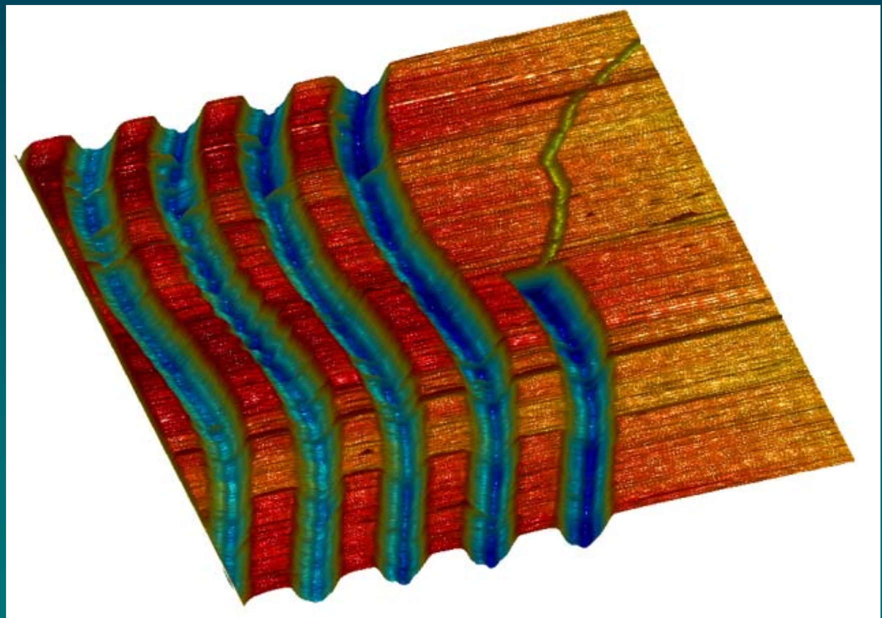
UNIVERSITY OF Southampton
School of Engineering Sciences

Con-focal Scanning Systems for Precision Metrology: Some Novel Applications

J.W.McBride, April-May 2010.





The University of Southampton

UNIVERSITY OF Southampton
School of Engineering Sciences

- One of the top UK institutions for Electronic, Electrical and Mechanical Engineering teaching Programmes.
- One of the top UK institutions for Engineering and Engineering Science Research.
- John McBride.
  - Instrumentation, Sensors, and Optical Metrology.
  - Electrical Contact Science, Arcing Devices.
  - Spin-out companies.
    - TaiCaan Technologies, Optical Metrology.
    - TaiCaan Research, High Speed Imaging, and Sound Archive.

UNIVERSITY OF Southampton
School of Engineering Sciences

Research Profile of Engineering at University of Southampton

UNIVERSITY OF Southampton
School of Engineering Sciences

HEFCE RAE'2001 in Engineering

• Electronics & Electrical	Grade	5*	67 Staff
• Computer Science	Grade	5*	19 Staff
• Engineering Sciences & ISVR Awarded "very best "5* (6*) rating in 2004	Grade	5*	100 Staff
• Civil	Grade	5*	19 Staff

- 5* Soton 205, IC 161, Cam 124, UCL 89, Oxf 77, Bath 40, Leeds 53, etc

UNIVERSITY OF Southampton
School of Engineering Sciences

RAE2008 results (SES+ISVR)

- Quality profile

4*	3*	2*	1*	U
15%	45%	35%	5%	0%

- Grade point average 2.7
- Staff submitted: 132.5

Changes 2001-2008

	2001	2001 FTE	2008 GPA	2008 FTE
Bath	5* A	40.4	2.6	43.4
Imperial	5* B	66.3	3.05	67
Leeds	5* B	23.5	2.9	40.5
Liverpool	5* A	21	2.7	23.0
Southampton	5* A	100.1	2.7	132.5
QU Belfast	5* B	16	2.75	25

UNIVERSITY OF Southampton
School of Engineering Sciences

RAE2008 Summary

- Southampton is Top 3 for Engineering overall
- 2nd in Mechanical, Aeronautical & Manufacturing Engineering (ranked by QR funding, 'power', 'medals' or number of academics rated 'internationally leading')
- 100% of staff submitted
- 30% increase in FTE 2001-2008
  - investment in talented new academics

UNIVERSITY OF Southampton
School of Engineering Sciences

UK University Guide Rankings

- Mechanical Engineering (includes Aeronautics & Astronautics, Ship Science)
  - 1st in The Guardian University Guide 2010
- Electronics & Electrical
  - 3rd in The Guardian University Guide 2010
- Computer Science
  - 5th in The Guardian University Guide 2009
- Civil Engineering
  - 3rd in The Guardian University Guide 2009

High quality undergraduate student body (AAA/AAB UG intake across Engineering)

University of Southampton
School of Engineering Sciences

Back to the Talk.

UNIVERSITY OF Southampton
School of Engineering Sciences

Outline

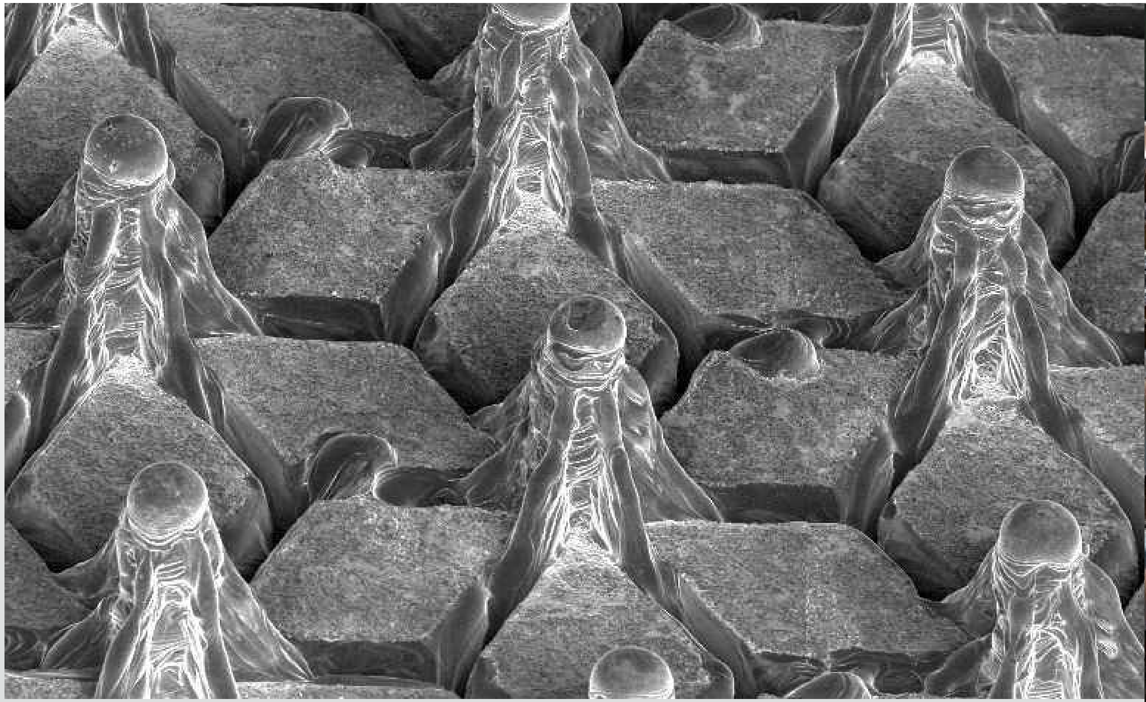
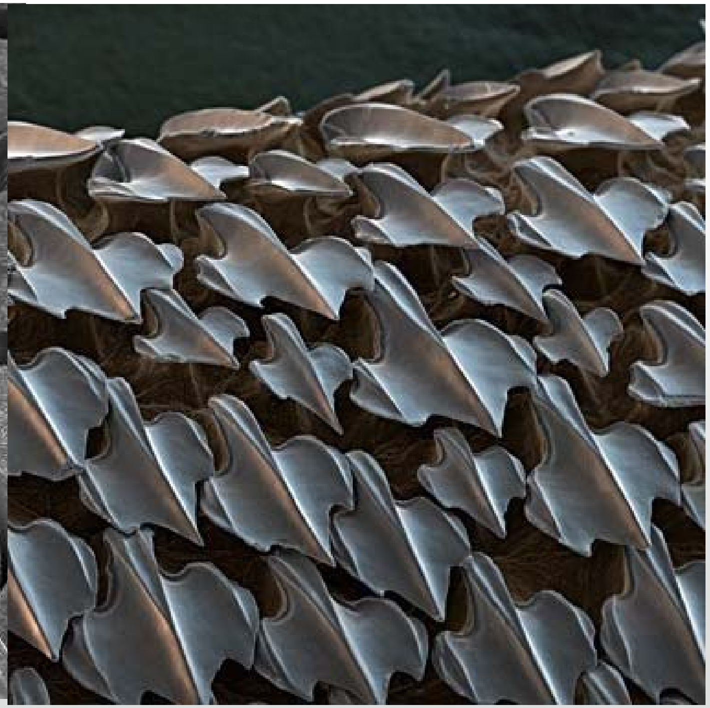
- Introduction Confocal methods
- TaiCaan Technolgies
- Aspheric Surfaces
- Surfaces and Early Sound Recordings
- Grooved Surfaces
- Carbon-nano tubes
- Free Form and Structured Surfaces
- Wear Analysis.

Research Directions

UNIVERSITY OF Southampton
School of Engineering Sciences

- How to accurately measure the 3D geometries of structured surfaces. The key limitation is in the sensing of reflected light from highly sloping surfaces.

- How to collect sufficient data to represent the functionality of a surface .

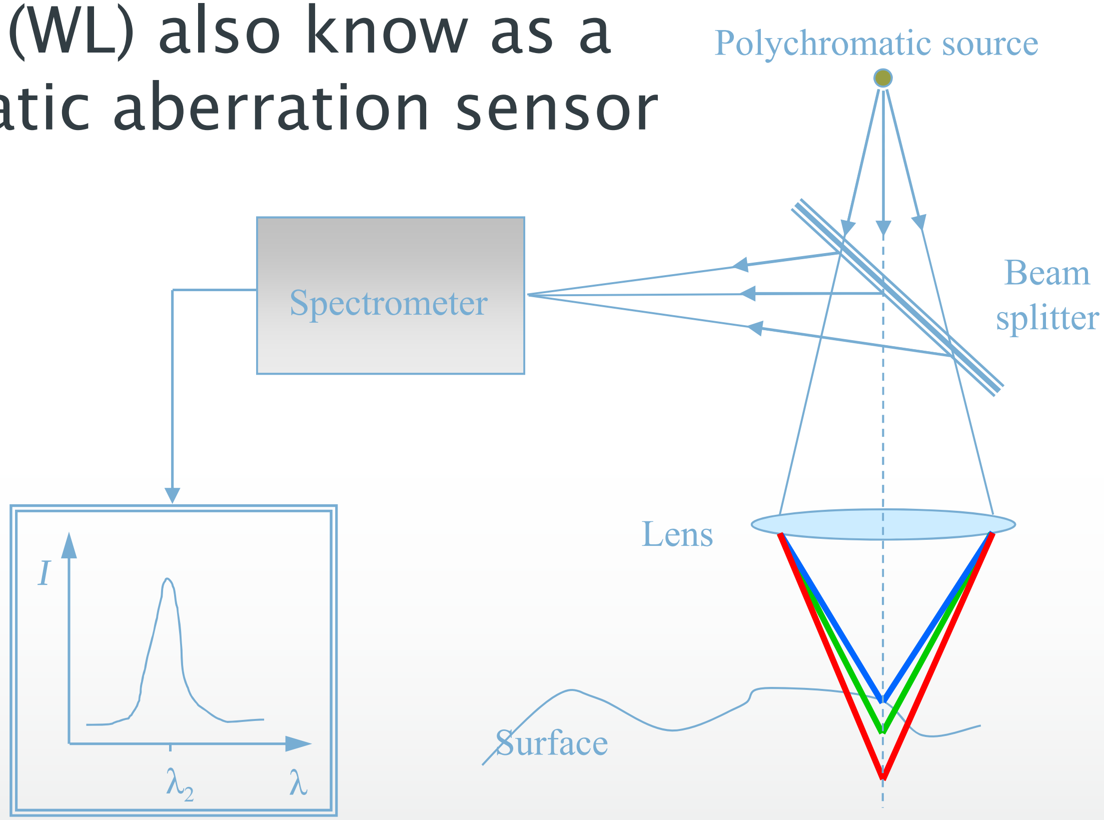
UNIVERSITY OF Southampton
School of Engineering Sciences

Confocal laser scanning microscopy (**CLSM** or **LSCM**) is a technique for obtaining high-resolution optical images with depth selectivity.

The key feature of confocal microscopy is its ability to acquire in-focus images from selected depths, a process known as optical sectioning. Images are acquired point-by-point and reconstructed with a computer, allowing three-dimensional reconstructions of topologically-complex objects.

SENSOR (1) Con-Focal White Light (WL) also know as a chromatic aberration sensor

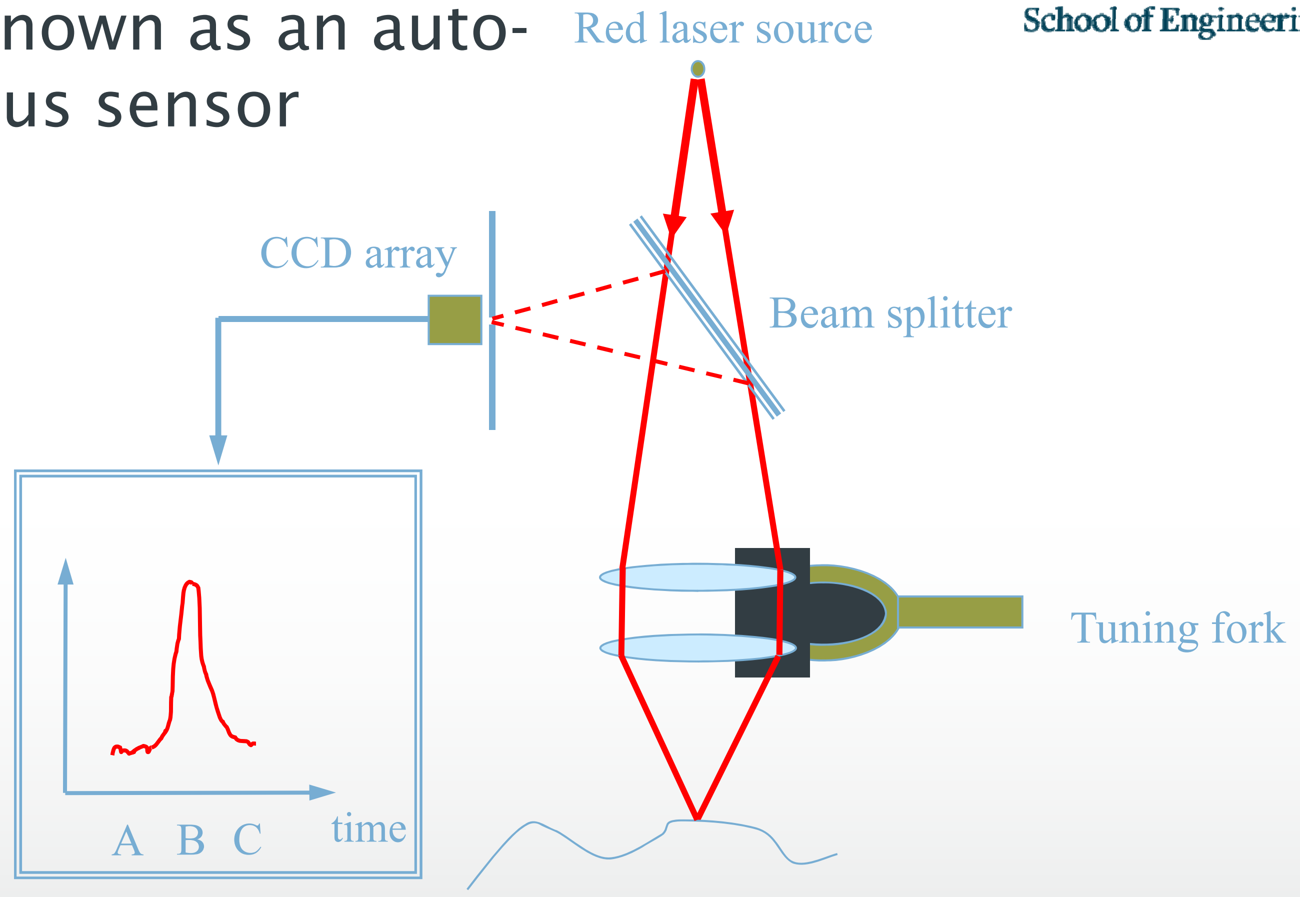
UNIVERSITY OF Southampton
School of Engineering Sciences



Schematic of the measurement principle for the WL system

SENSOR (2) Con-Focal Laser (CL) also known as an auto-focus sensor

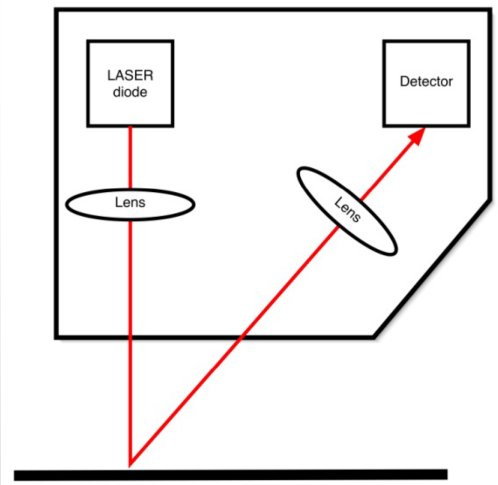
UNIVERSITY OF Southampton
School of Engineering Sciences

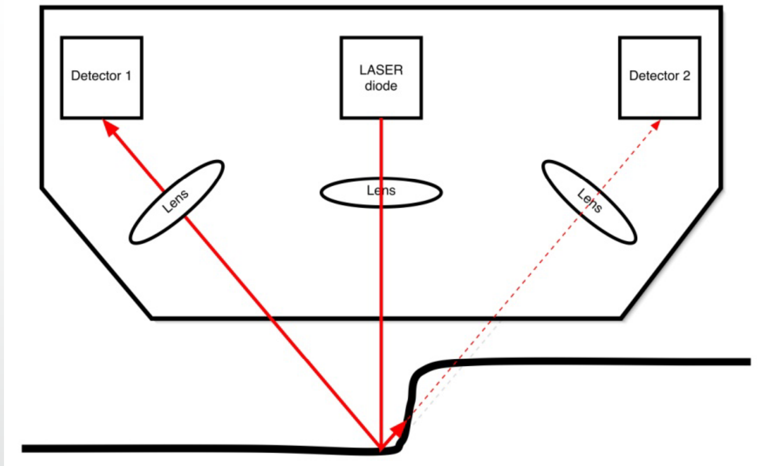


Schematic of the measurement principle for the CL

Triangulation Laser Sensor (3)

- Shadows: e.g. MEMS etched channel
- Laser triangulation sensor unable to discern certain orientations of surface features:





UNIVERSITY OF Southampton
School of Engineering Sciences

Sensor study: sensor comparison parameters

Sensor	Spot size (μm)	Sample frequency (kHz)	Gauge range (mm)	Angular Tolerance	Axial resolution (nm)
TL	30	2	10	>60	1000
CL	2	1.4	0.6	17°	10
WL	7	1 -4	0.35	27°	10

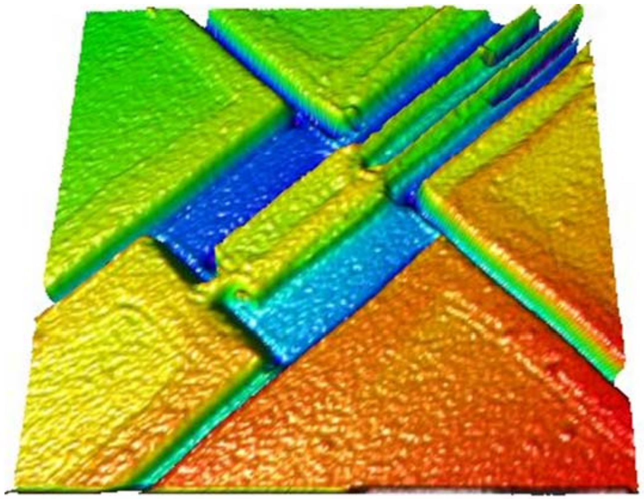
The Selected sensing technology is the WL system

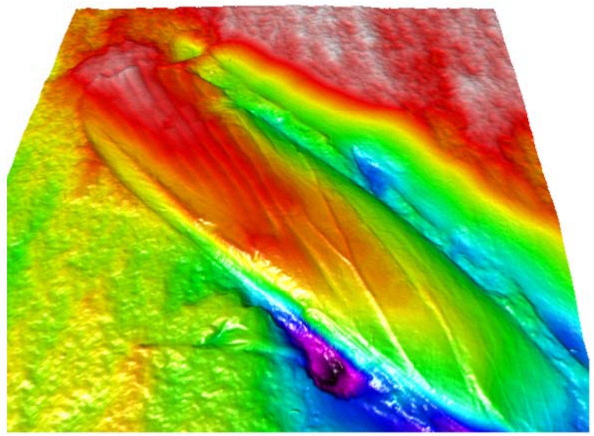
- Best Angular tolerance for a given resolution and gauge range.
- Capable of 4kHz sampling.

TAICAAN TECHNOLOGIES

Specialists in High Quality,
High Precision,
Optical Surface Profilers

www.taicaan.com

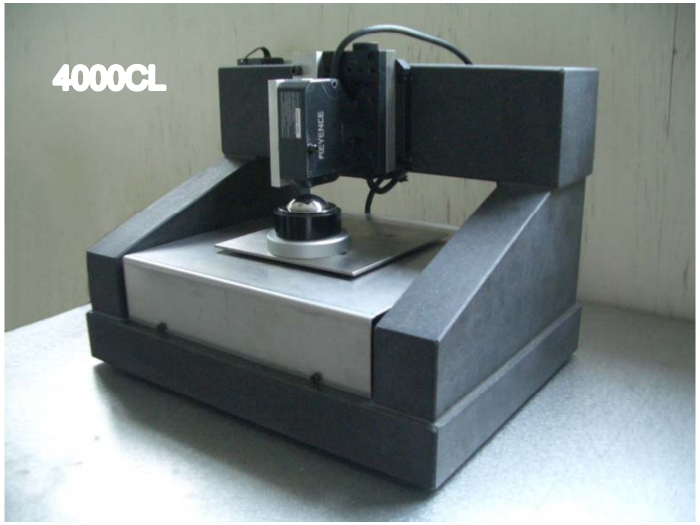


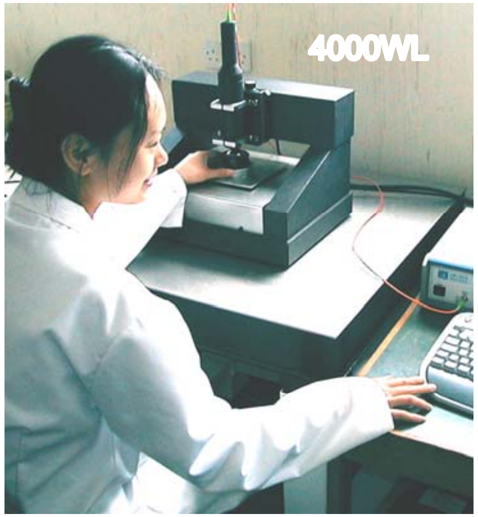


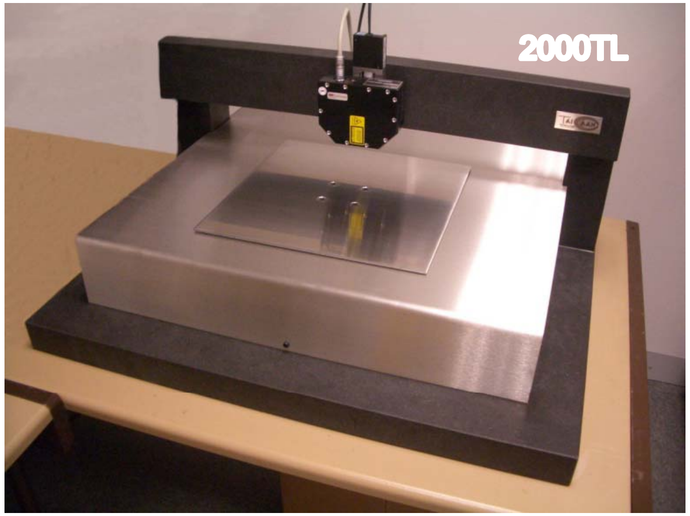
TaiCaan 24.0 mm x 24.0 mm 601 x 601

Surface Metrology

- **Standard Products**
  - XYRIS 4000 (Compact System) CL and WL
  - XYRIS 2000 (TL CL or WL)
  - Con-focal Sensors with sub micron resolution
  - For MEMS, Optical Components, wear analysis.







TAICAAN TECHNOLOGIES

User Perspective

- Single user interface for all systems.
- Normally the motion system, moves the object in the X,Y plane, under the sensor. A 3D data set is constructed to image the surface, and full data analysis provided with a separate software package. BODDIES™
- All motion systems are DC servo controlled, with feedback from the X and Y table position.
- The X,Y resolution is normally 100nm, over a range of 25-300mm.
- Therefore the field of view is controlled by the user not by the NA of the optics used.

Systems (1) XYRIS 4000 CL/WL

➔ Compact and portable system

➔ Motions system range 25mm in X,Y,Z.

➔ Sensor resolution 10nm.

➔Axes resolution 100nm, can be 10nm.

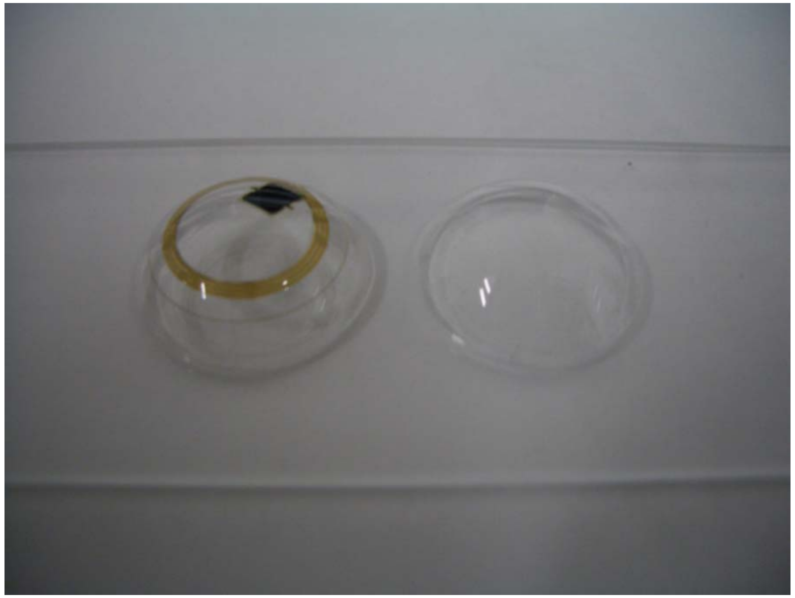
➔ Ideal for precision components

➔ Supplied with single or dual head sensor

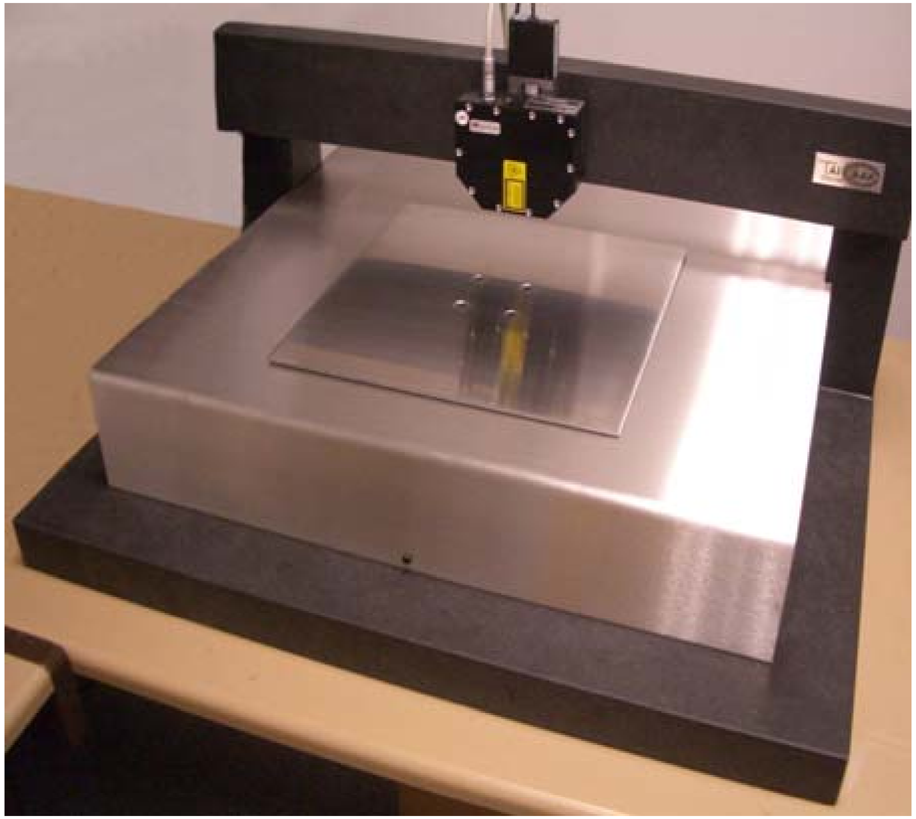
➔ CL includes CCD camera

TAI CAAN TECHNOLOGIES

Example application. Lens Thickness



System (2) XYRIS 2000 TL/WL/CL



- Standard System TL
- Motion system range 50mm-300mm in X,Y, typically 25mm in Z.
- Axes resolution 100nm.
- Ideal for large scale objects.
- Can be supplied with dual head sensors.

System (3) XYRIS 6000 CL/WL

- High End Air bearing system with Linear Motors.
- Motion System Range 350mm in X,Y and 25mm in Z.
- 0.1nm axes resolution
- Ideal for high speed large area measurements.

UNIVERSITY OF Southampton
School of Engineering Sciences

The 3D Measurement and Analysis of Aspheric Surfaces

Some Related Refs

University of Southampton
School of Engineering Sciences

- McBride, J.W. (2009) The 3D measurement and analysis of aspheric surfaces. At, *NPL Engineering Measurement Awareness Network Meeting: High Accuracy Freeform Measurement of Optical and Orthopaedic Surfaces, Loughborough, UK 29 Jan 2009.* , 39pp.
- Sun W, Hill M and McBride J.W. (2008) An investigation of the robustness of the nonlinear least-squares sphere fitting method to small segment angle surfaces. *Precision Engineering*, 32, (1), 55-62. (doi:10.1016/j.precisioneng.2007.04.008)
- Sun, W., McBride, J.W. and Hill, M. (2010) A new approach to characterising aspheric surfaces. *Precision Engineering*, 34, (1), 171-179. (doi:10.1016/j.precisioneng.2009.05.005)
- Hill, M., Jung, M. and Mcbride, J.W. (2002) Separation of form from orientation in 3D measurements of aspheric surfaces with no datum. *International Journal of Machine Tools & Manufacture*, 42, (4), 457-66.
- Jung, M., Cross, K.J., McBride, J.W. and Hill, M. (2000) A method for the selection of algorithms for form characterisation of nominally spherical surfaces. *Precision Engineering*, 24, (2), 127-138.
- McBride, J.W. and Cross, K.J. (1996) The measurement and analysis of the three-dimensional form of curved surfaces. *International Journal of Machine Tools Manufacture*, 36, (5), 597-610.

Defining the Aspheric Surface

UNIVERSITY OF Southampton
School of Engineering Sciences

A rotationally symmetrical surface that gradually varies in surface power from the centre towards the edge in a radial fashion.

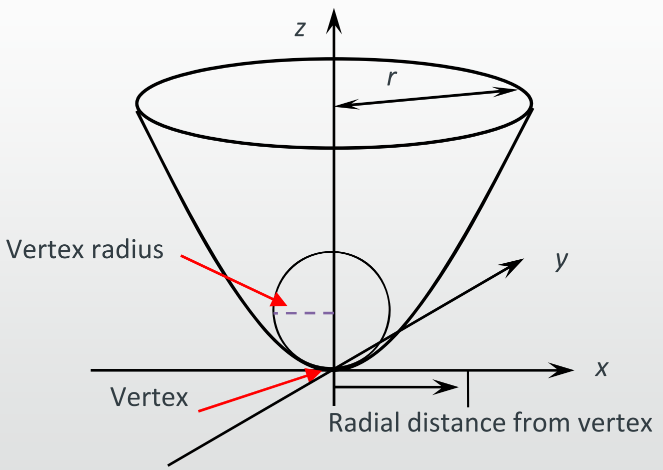
$$z = \frac{cr^2}{1 + \sqrt{1 - (1 + k)c^2 r^2}} + A_4 r^4 + A_6 r^6 + A_8 r^8 + A_{10} r^{10} + A_{12} r^{12} \quad (1)$$

$$r = \sqrt{x^2 + y^2}$$

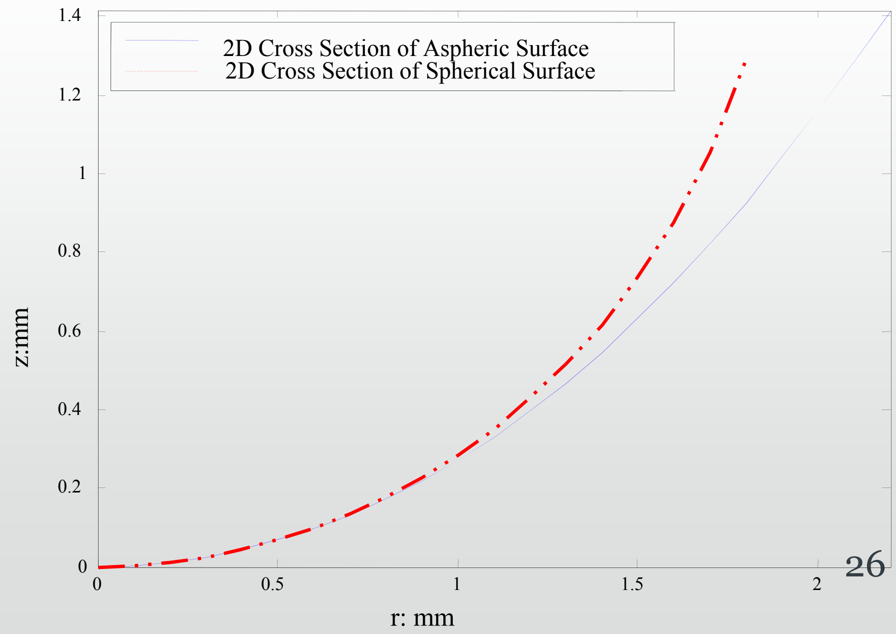
k is the conic constant

c is the reciprocal of vertex radius (1/R)

A_4 A_6 A_8 A_{10} A_{12} are polynomial coefficients



Schematic of an aspheric surface



UNIVERSITY OF Southampton
School of Engineering Sciences

The Measurement Problem.

EXTREME--Large and Nano optics

UNIVERSITY OF Southampton
School of Engineering Sciences

Surface Manufacture | Surface Measurement | Surface Characterisation

Selection of measurement system

Contact method

1. Stylus--Taylor Hobson
   - Allow large surface angles and areas to be measured

     New: swing arm profilometer are being developed to measure large optics (UCL, NPL & Zeeko Ltd)
   - Measurement setup relatively flexible

   Error resources:
   - Shape of stylus head
   - …

   Disadvantage
   - Scratch soft surfaces

Non-contact method

1. Interferometer
   - High reliability
   - Have difficulty in measuring
   - System set up complicated

   Error resources:
   - Manufacture of CGH or null lenses

2. Optical scanning systems
   - Fast scanning speed
   - Flexible measurement setup

   Error resources:
   - Sensor errors
   - Table errors
   - System alignment errors

3D Non-Contact Measurement Methods

- Interferometry- relative to a reference surface, usually spherical. Issues of angular tolerance.
- Holographic references. These are expensive and relate to a specific surface. Each surface type requires a new reference.
- Con-focal Sensors. Limited by angular tolerance and quality of motion system.

UNIVERSITY OF Southampton
School of Engineering Sciences

The Analysis Problem.

EXTREME--Large and Nano optics

UNIVERSITY OF Southampton
School of Engineering Sciences

Surface Manufacture | Surface Measurement | Surface Characterisation

Pre-processing the data

Direct comparison between design and measured surfaces

- Information of design surface required
- Surface area out of measurement limits can not be compared

Simplified models

- Sphere model—can only be used when the measured surface form close to spherical surfaces
- Polynomial model
  - Close to design surface form

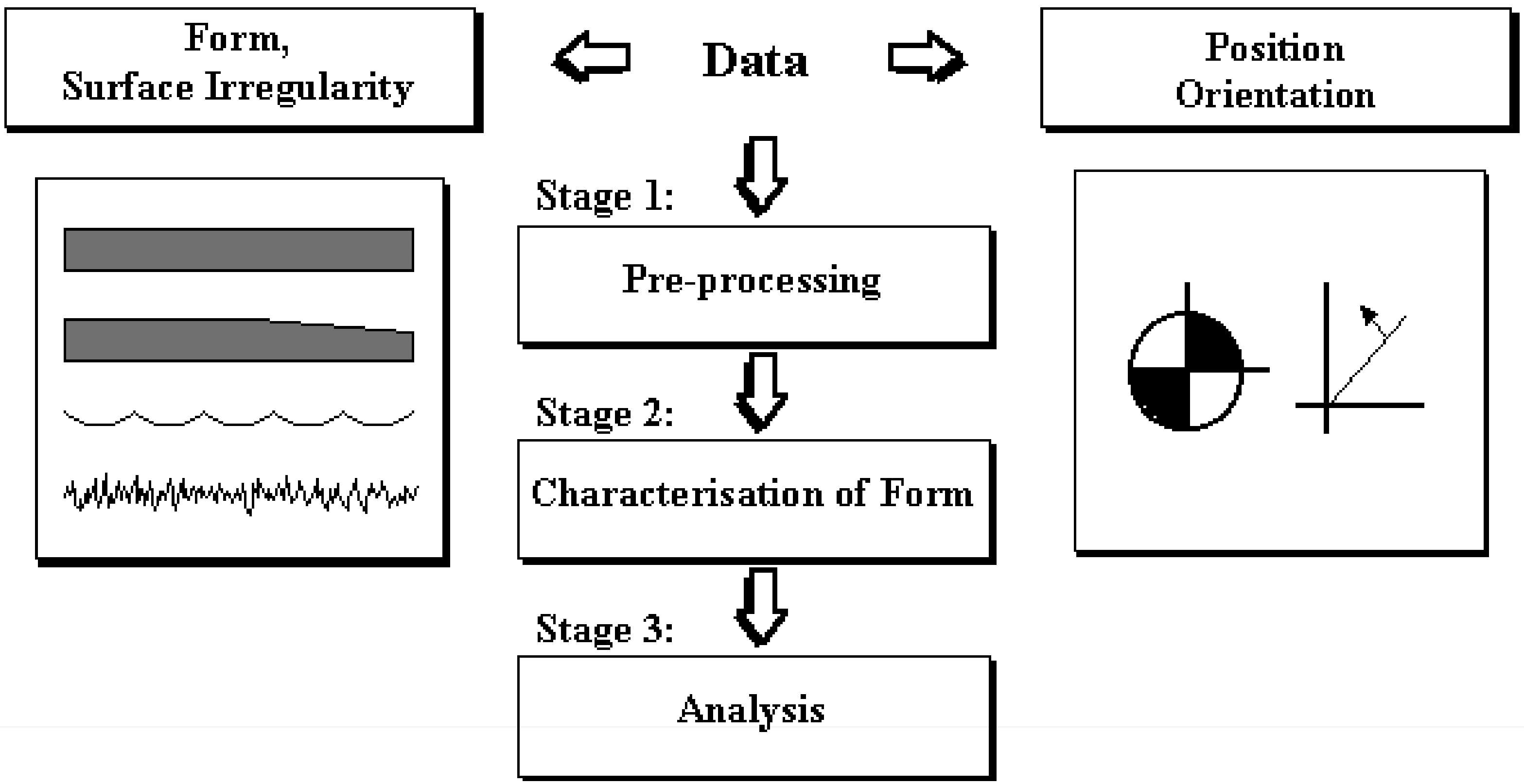
Model has to be reconsidered once the measured surface area changed.

Total aspheric fit—developing

- Allow surface parameters to be compared to design value
- Allow information of measured surface to be stored
- Allow measured surface to be recreated
- Allow surface information can be used in optics software such as ZEMAX

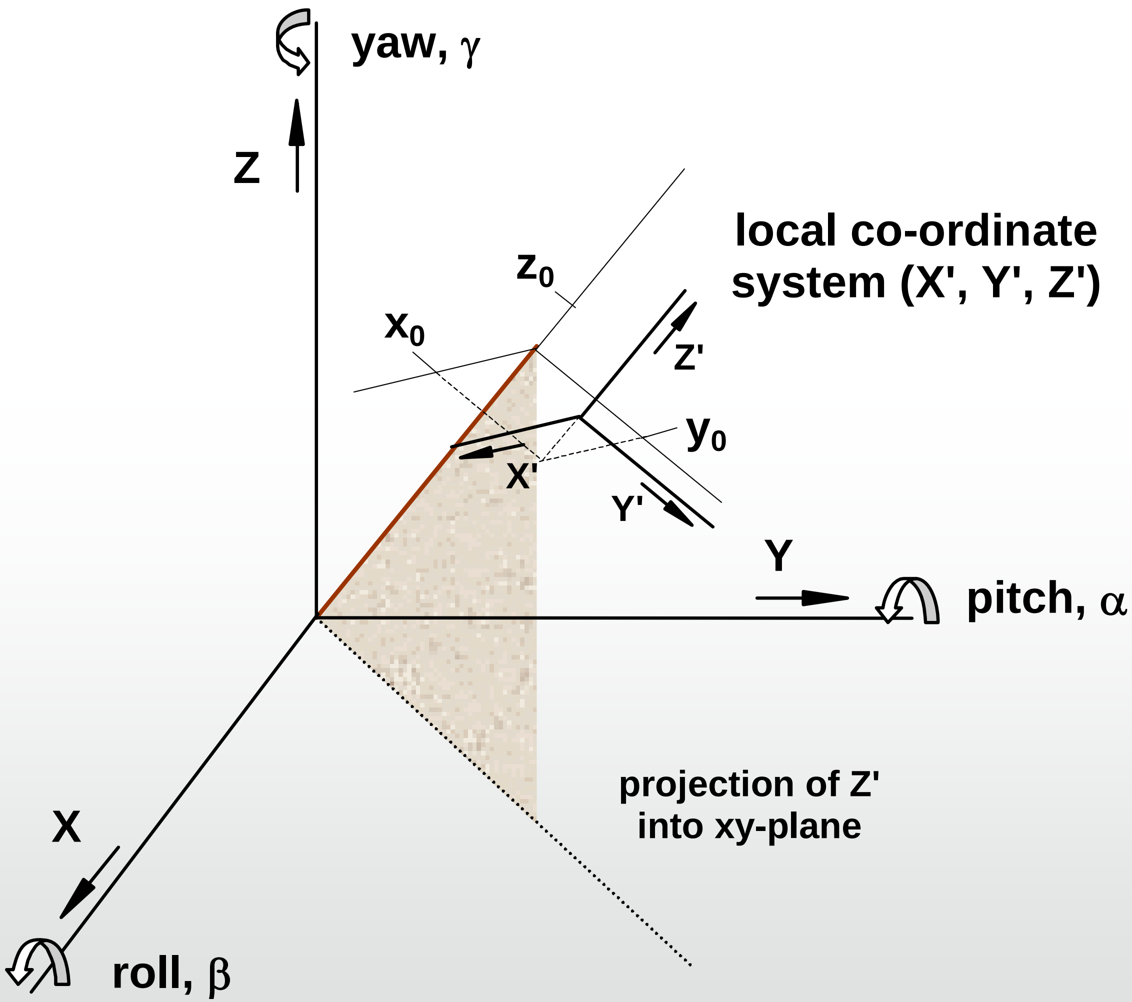
- 2D parametric solutions have been used for a number of years.
- The aim was to develop 3D parametric solutions, such that, measured surfaces can be compared to designed surfaces.
- This overcomes the subjectivity of using the residual or error map in defining the measured surface.
- The parameterised surface can be used to define changes to the manufacturing process.

Interpretation of the Data



Pre-Processing Methods

UNIVERSITY OF Southampton
School of Engineering Sciences



- Local axis Search*
- Contour Line Fit
- Lowest Point

*Hill, M., Jung, M. and Mcbride, J.W. (2002) Separation of form from orientation in 3D measurements of aspheric surfaces with no datum. *International Journal of Machine Tools & Manufacture*, 42, (4), 457-66.

Fitting to Aspheric Surfaces

UNIVERSITY OF Southampton
School of Engineering Sciences

- Assumes a Pre-processing Stage
- Direct comparison method
  - Require surface design information
- Simplified model
  - Selection of model is critical and time consuming
  - Estimated parameters cannot be compared with design values
- Total aspheric surface fitting algorithm

  (1) Indirect method-based on the nonlinear least-squares sphere fitting algorithm

  (2) Direct method (Total Aspheric Surface Fitting Algorithm)*

  - Surface area out of maximum measurable areas can be estimated
  - Allow surface information to be stored
  - Estimated parameters can be compared with design values
  - Estimated parameters can be used for design and quality control purposes.

*Sun, W., McBride, J.W. and Hill, M. (2009) A new approach to characterising aspheric surfaces. *Precision Engineering*, 40pp. (In Press)

Defining the Aspheric Surface

UNIVERSITY OF Southampton
School of Engineering Sciences

A rotationally symmetrical surface that gradually varies in surface power from the centre towards the edge in a radial fashion.

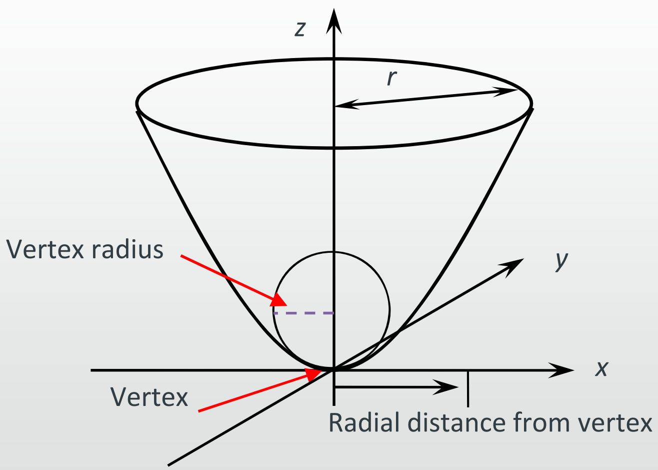
$$z = \frac{cr^2}{1 + \sqrt{1 - (1 + k)c^2 r^2}} + A_4 r^4 + A_6 r^6 + A_8 r^8 + A_{10} r^{10} + A_{12} r^{12} \qquad (1)$$

$$r = \sqrt{x^2 + y^2}$$

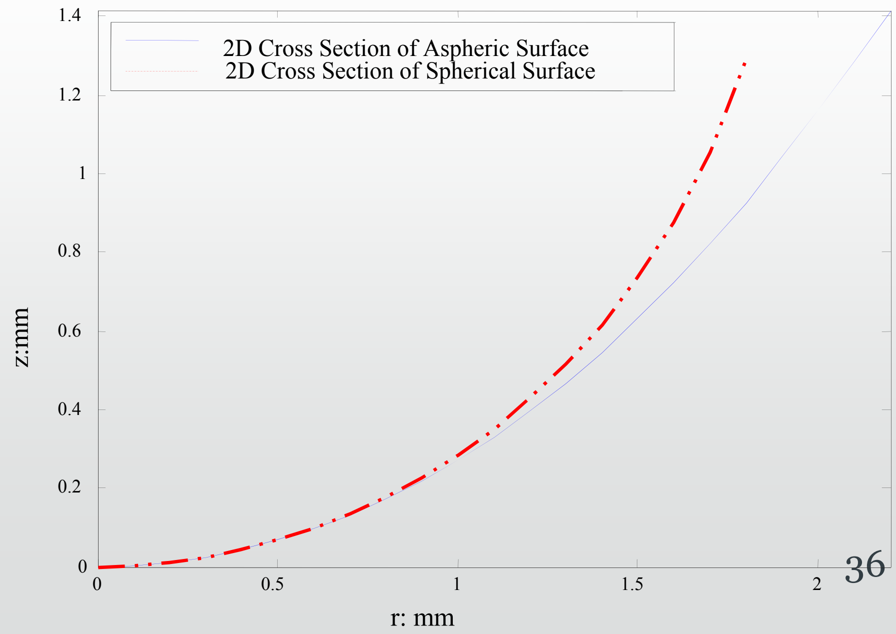
k is the conic constant

c is the reciprocal of vertex radius (1/R)

A_4 A_6 A_8 A_{10} A_{12} are polynomial coefficients

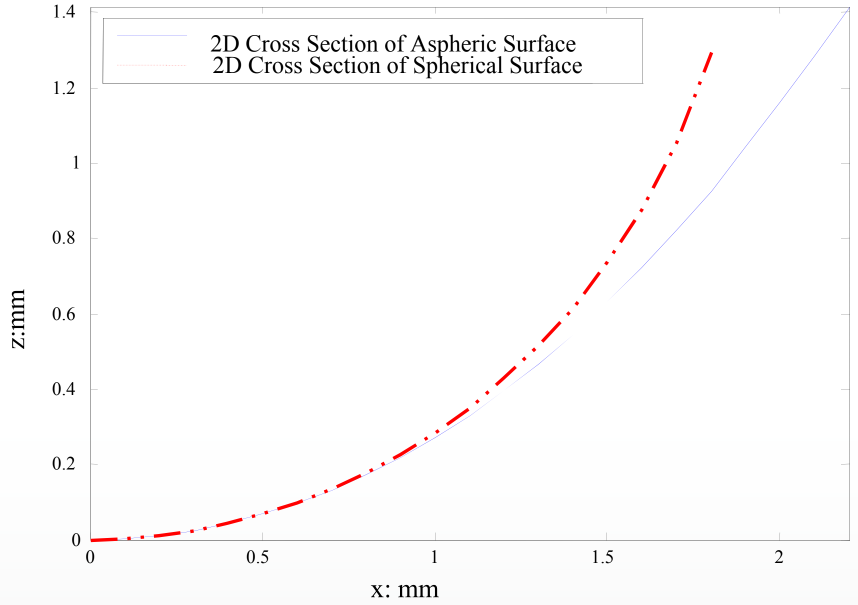


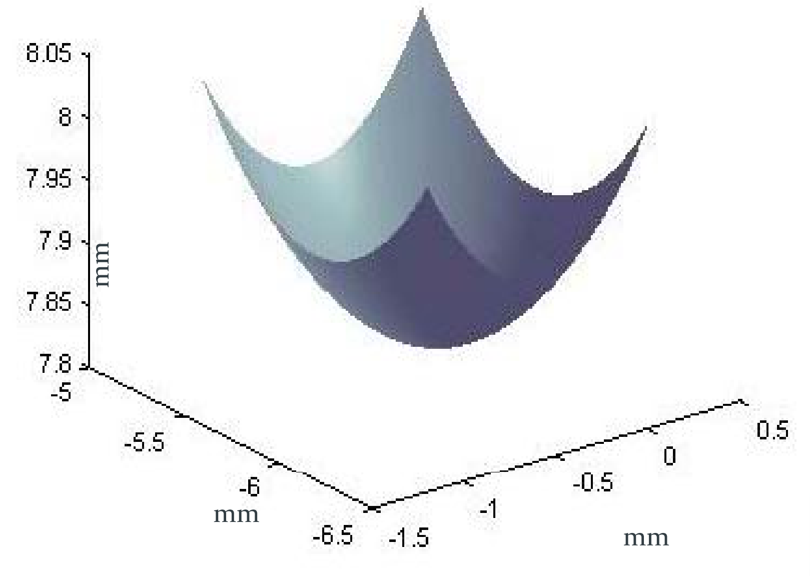
Schematic of an aspheric surface

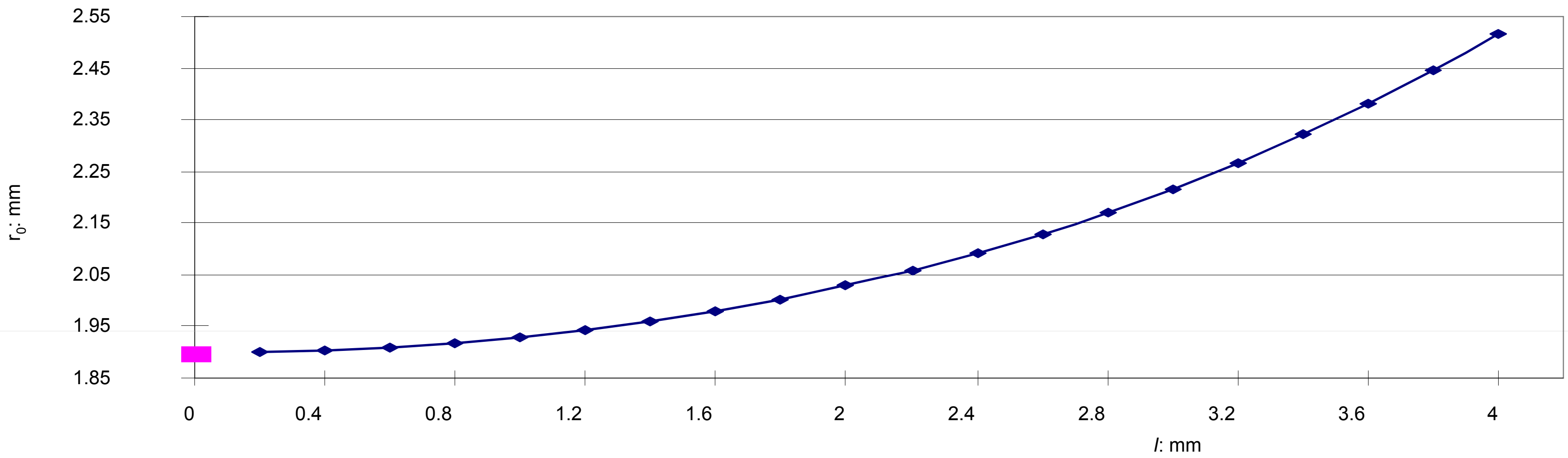


1. Indirect Aspheric Fitting Algorithm

UNIVERSITY OF Southampton
School of Engineering Sciences

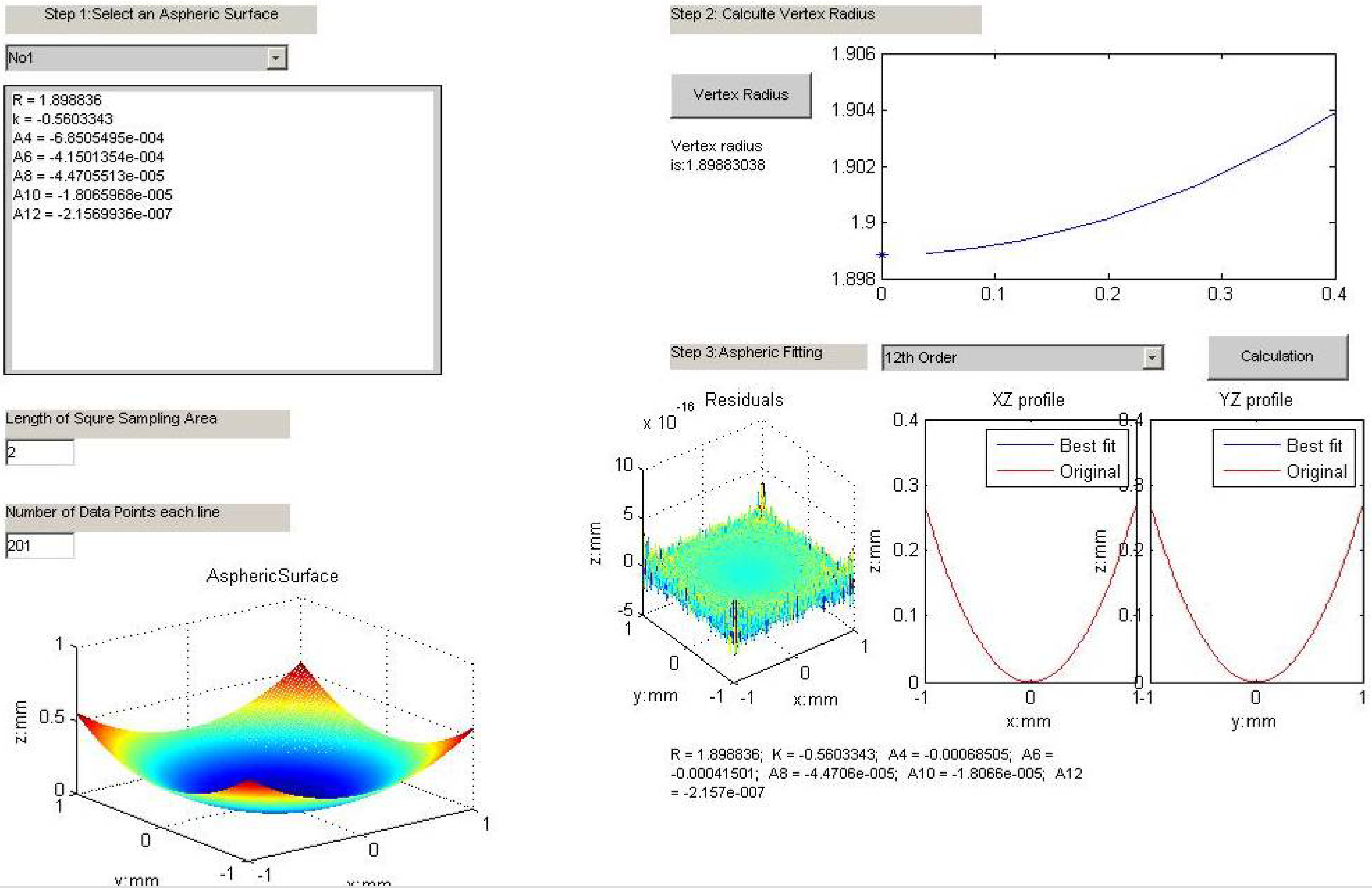






1. Indirect aspheric fitting method

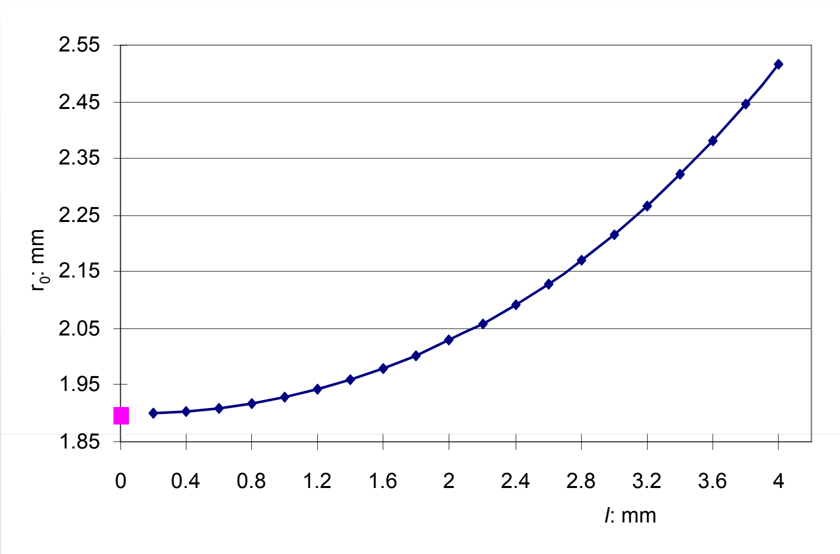
UNIVERSITY OF
Southampton
School of Engineering Sciences



UNIVERSITY OF Southampton
School of Engineering Sciences

Potential Problems in Real Surfaces

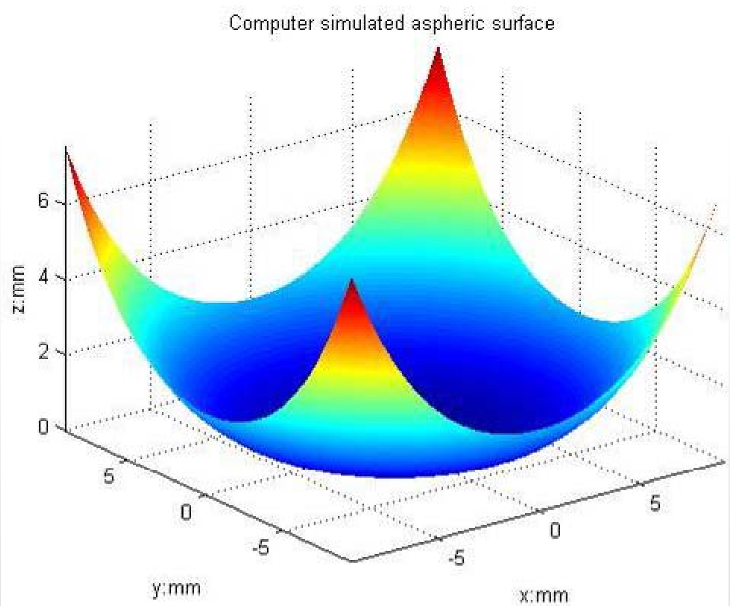
- The pre-processing method.
- The surface noise (sensor and motion system) combined with the Bias and Uncertainty associated with fitting sphere to small segment angle surface will result in uncertainty in the evaluation of the vertex radius R

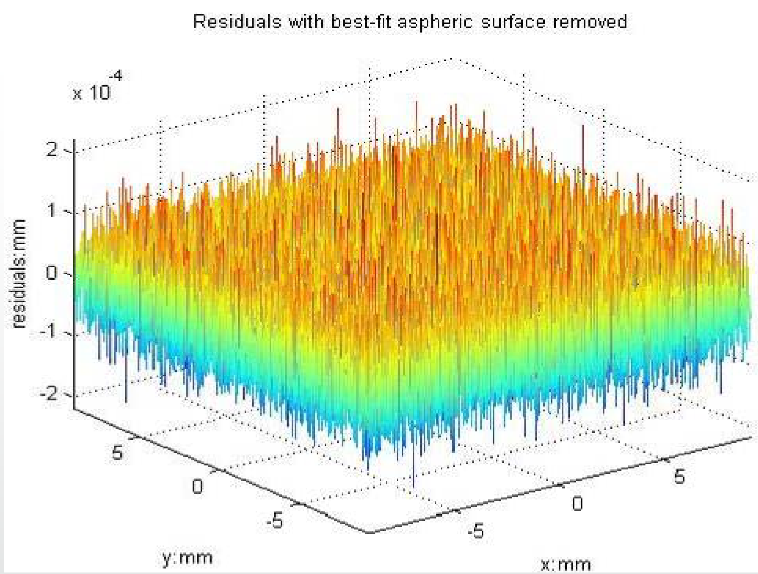


2. Direct aspheric surface fitting method

University of Southampton
School of Engineering Sciences

	R	K	A_4	A_6	*Noise(std)*
Designed	44.577884	-1.710312e+2	2.316294e-4	3.495852e-8	50 nm
Estimated	44.578034	-1.710267e+2	2.316284e-4	3.496336e-8	49.9991 nm





Fitting results of a 6th order aspheric surface superimposed with surface noise.
(Left): Simulated 6th order aspheric surface. (Right): Residuals with the best-fit 6th order surface removed

Potential Problems in Real Surfaces

- The pre-processing method.
- The surface noise (sensor and motion system) will result in uncertainty in the evaluation, however the method offers improved performance over the Indirect method.

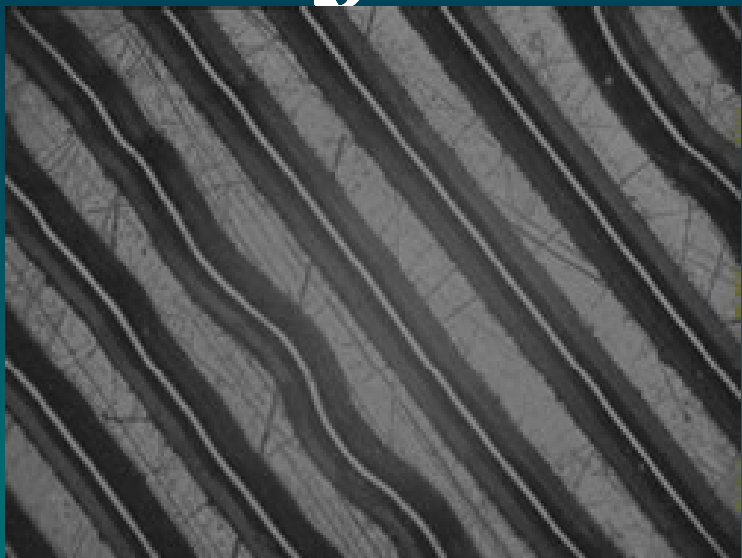
UNIVERSITY OF Southampton
School of Engineering Sciences

Future Studies

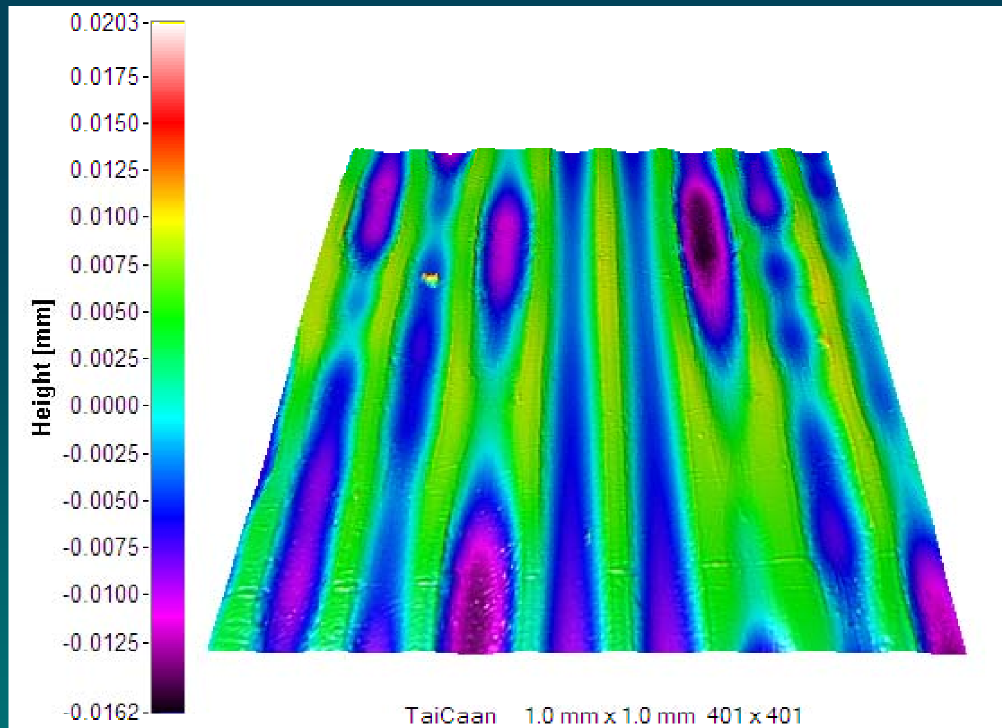
- To develop the direct aspheric fitting algorithm TAFD.
  - Investigate the algorithm performance over a wide range of surface parameters,
  - Quality of fitting: efficiency and accuracy
  - Fitting results: the bias and the uncertainty properties
- To investigate the reliability of the measurement machine.
  - To study the dominant systematic errors and the effect on measuring curved surfaces
- To optimise the pre-processing of measured data, and the link to the scanning process.
  - Sampling strategies
  - Alignment techniques
- To implement proposed fitting algorithm on measured aspheric surfaces
  - Investigate real measured surfaces
  - To develop analysis tools for fitting aspheric surfaces
  - To develop methods for linkage and feedback to manufacturing processes.

UNIVERSITY OF Southampton
School of Engineering Sciences

The Sound Archive Project



CCD image
of 78 surface



3D map of cylinder
surface

Selected Refs

UNIVERSITY OF Southampton
School of Engineering Sciences

- McBride, J.W. (2009) The sound archive project 2005-2009. At,*Society of Archivists Conference, Bristol, UK 01 - 04 Sep 2009.*
- Boltryk, P.J., Hill, M. and McBride, J.W. (2009) Comparing laser and polychromatic confocal optical displacement sensors for the 3D measurement of cylindrical artefacts containing microscopic grooved structures. *Wear*, 266, (5-6), 498-501. (doi:10.1016/j.wear.2008.04.082)
- McBride, J.W., Zhao, Z. and Boltry, P.J. (2009) A comparison of optical sensing methods for the high precision 3D surface profile measurement of grooved surfaces. In, *EUSPEN Special Interest Group Meeting: Structured and Freeform Surfaces, Edinburgh, UK 24 - 25 Feb 2009.* , 46pp.
- McBride, J.W, Zhao, Z. and Boltryk, P. (2008) A comparison of optical sensing methods for the high precision 3D surface profile measurement of grooved surfaces. In, *Proceedings ASPE 2008 Annual Meeting and the Twelfth ICPE.* Raleigh, USA, American Society for Precision Engineering.
- Nascè, Antony, Hill, Martyn, McBride, John W. and Boltryk, Peter (2008) A quantitative analysis of signal reproduction from cylinder recordings measured via noncontact full surface mapping. *Journal of the Acoustical Society of America*, 124, (4), 2042-2052. (doi:10.1121/1.2973238)
- Boltryk, P.J., McBride, J.W., Hill, M., Nascè, A.J., Zhao, Z. and Maul, C. (2008) Non-contact surface metrology for preservation and sound recovery from mechanical sound recordings. *Journal of the Audio Engineering Society*, 56, (7/8), 545-559.
- Boltryk, Peter J., Hill, Martyn, McBride, John W. and Nascè, Antony (2008) A comparison of precision optical displacement sensors for the 3-D measurement of complex surface profiles. *Sensors and Actuators A: Physical*, 142, (1), 2-11. (doi:10.1016/j.sna.2007.03.006)

4 Year Project 2005-09

UNIVERSITY OF Southampton
School of Engineering Sciences

- Collaborations with.
- British Library. Nigel Bewley and Wil Prentice
- Lawrence Berkeley Lab. Carl Haber
- TaiCaan Technologies
  - Kevin Cross
- University of Southampton.
  - Prof. Martyn Hill
  - Dr. Peter Boltryk
  - Samantha Zhao, and Antony Nasce.

TAICAAN TECHNOLOGIES

UNIVERSITY OF Southampton
School of Engineering Sciences

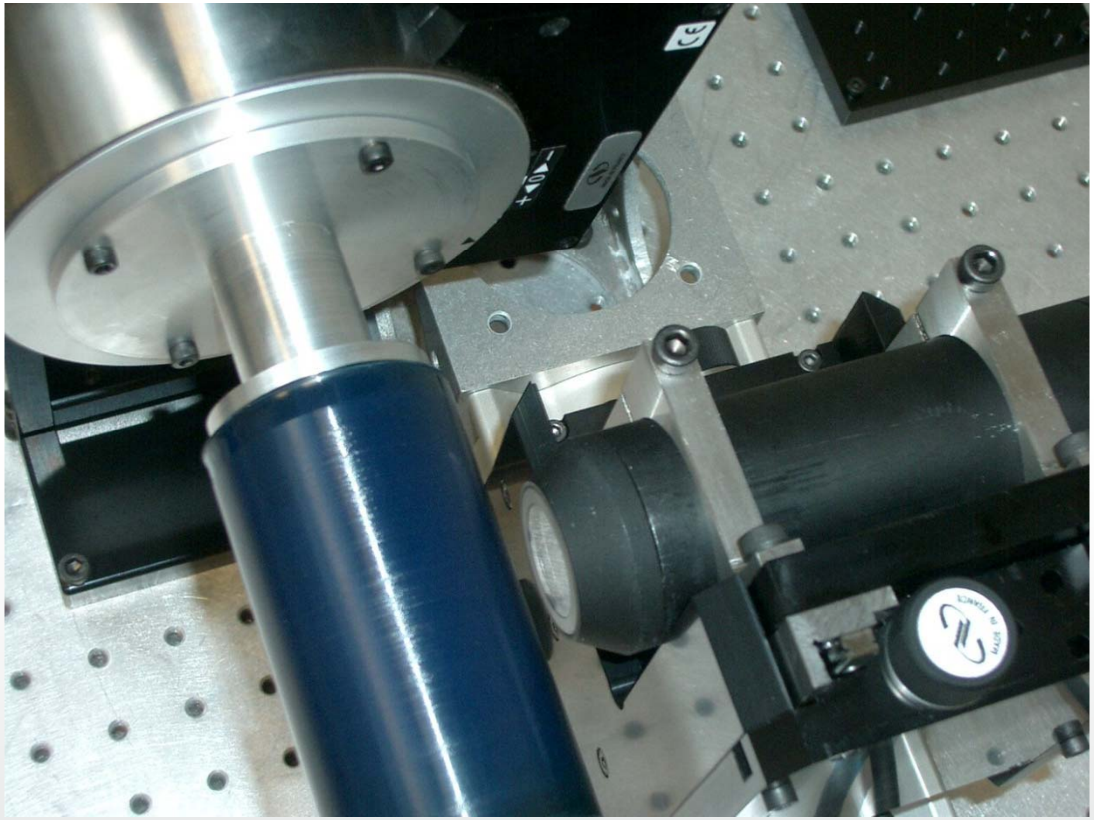
The Sound Archive Project

- Non-Contact Surface Measurement. Development of metrology systems for mapping the surface topology of cylinders and flat discs. PRESERVATION.
- Sensor Development. Design of optical sensors with improved angular tolerance and sensing speed.
- Audio Signal Recovery. Methods of accurate sound reproduction from discrete surface maps of cylinders and discs.
- http://www.sesnet.soton.ac.uk/archivesound/

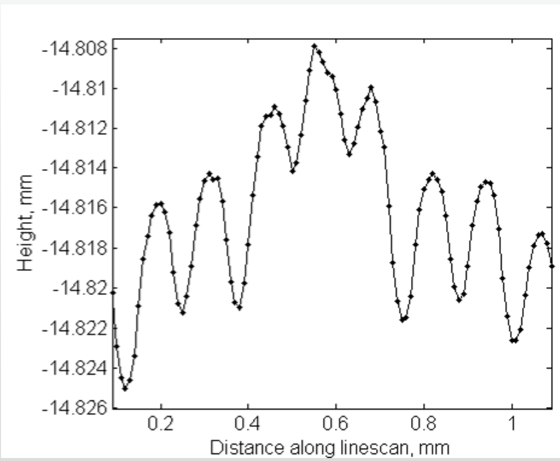
Scanning process – cylinders (1)

UNIVERSITY OF Southampton
School of Engineering Sciences

- Traverse displacement sensor along the cylinder axis
- Sensor measures the surface height across the grooves
- Acquire data 'on the fly' at fastest possible



General view of original cylinder system



Typical linescan profile

System Requirements

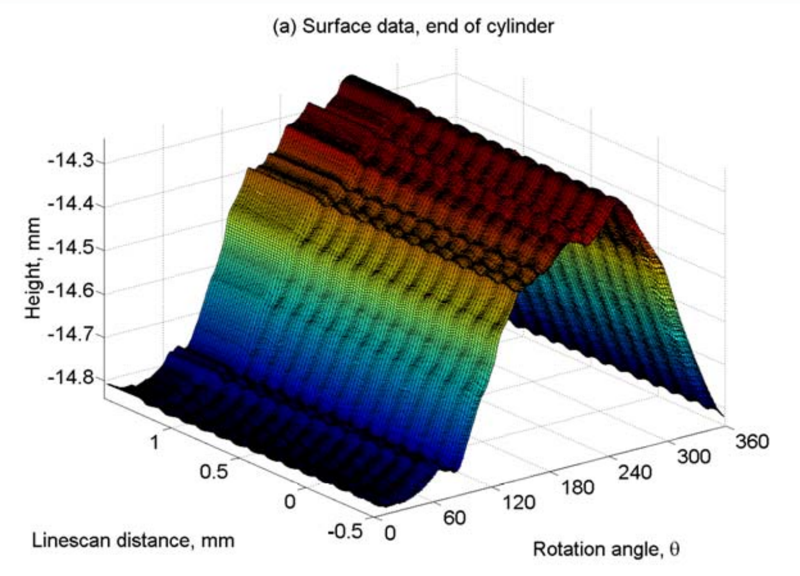
UNIVERSITY OF Southampton
School of Engineering Sciences

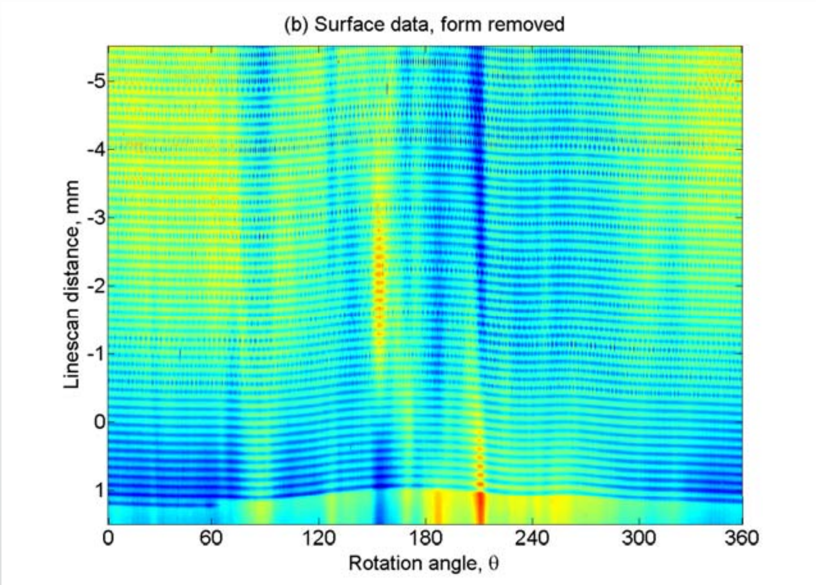
- Typical groove profile is 100μm wide by 40 μm depth
- 10μm spacing across the groove to define profile, but only for vertically modulated sound carriers
- 5μm spacing along the groove, to provide temporal sampling at 96kHz.
- Approximate Surface area 100mm x 150mm
- 150 Million data, sampled in 24 hours
- 4kHz, sensor sampling
- 10nm axial resolution required to define audio
- Angular Tolerance on Flat discs > 30°

UNIVERSITY OF Southampton
School of Engineering Sciences

Scanning process – cylinders (2)

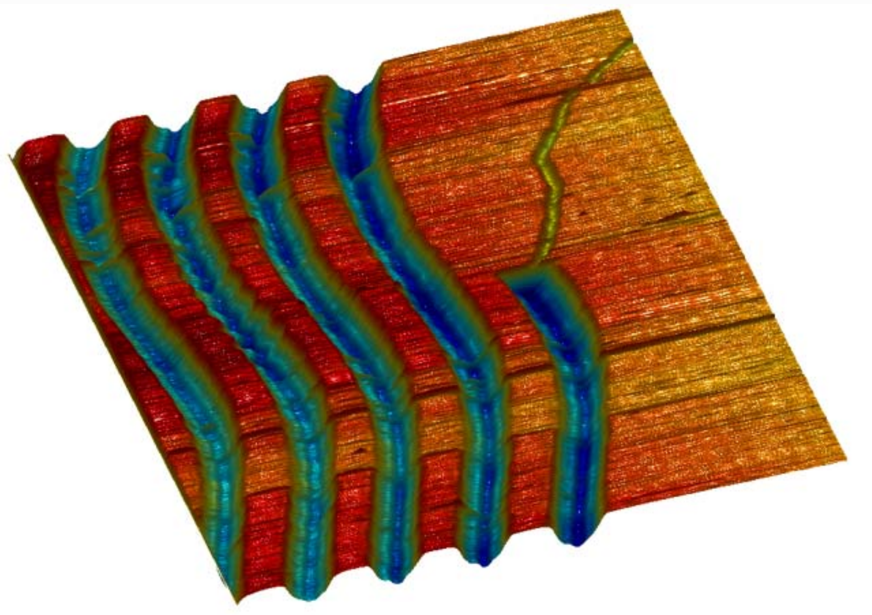
- Rotate the cylinder fractions of a degree between linescans
- Repeat for whole surface area
- Results in unwrapped rectangular surface topology





Victoria graphophone cylinder

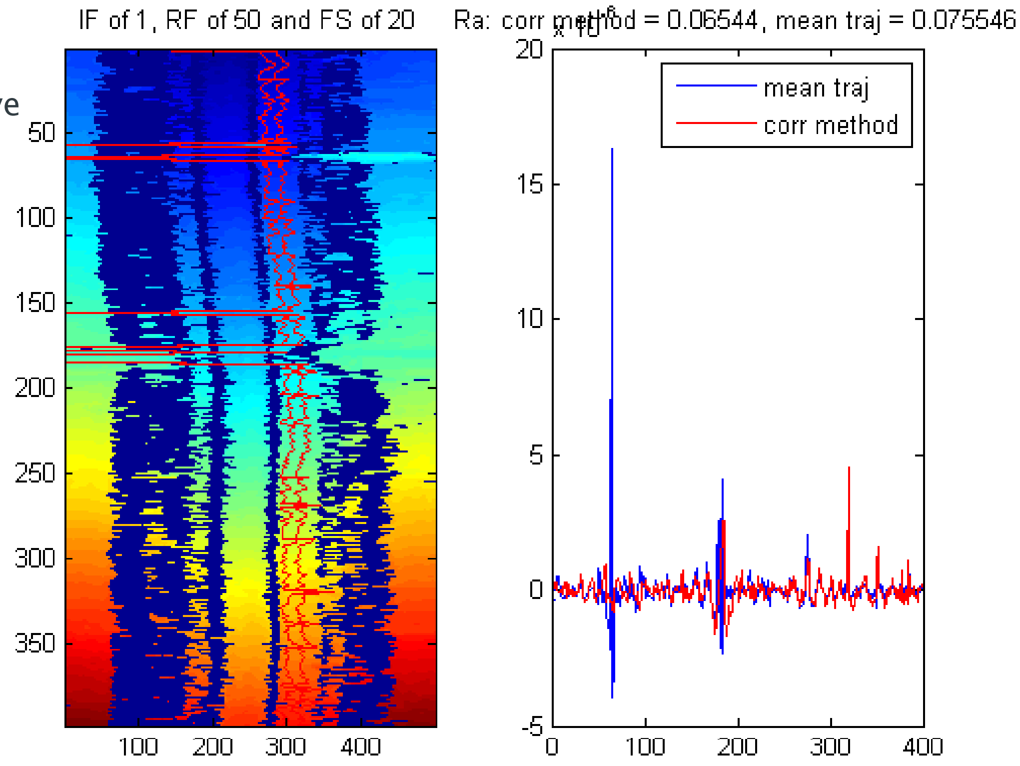
- Analysis of data to extract displacement signal from specific regions of the groove
- Uses correlation-based feature tracking method
- Main influence is to reduce impulsive noise
- Intelligibility not improved greatly
- Use speech enhancement technique

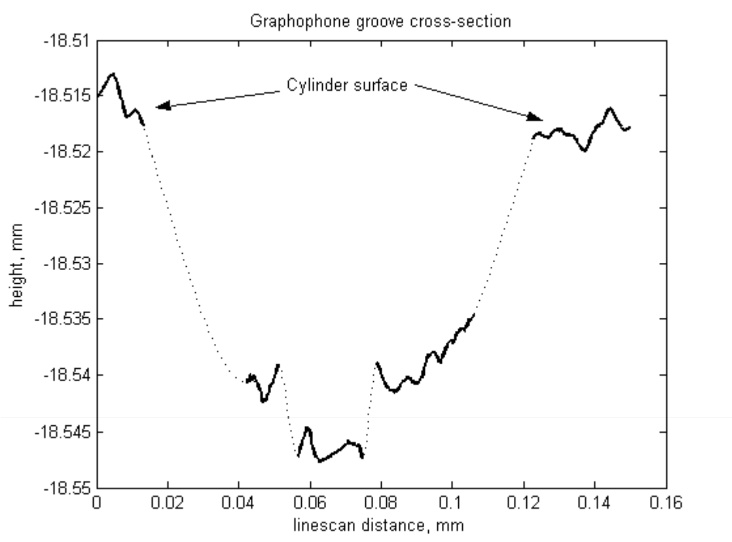


UNIVERSITY OF Southampton
School of Engineering Sciences

Victoria graphophone cylinder

Feature tracking used to extract audio from right hand plateau region of groove





Typical Victoria graphophone groove cross-section. Regions of data loss are interpolated using the dotted line for presentation clarity

UNIVERSITY OF Southampton
School of Engineering Sciences

Some sound clips…

- “Beautiful Birds Sing On”, 1905 (9022: Edison Gold Moulded Record)
- “Lonesome”, 1909 (1184: Indestructible Record)
- “My Wild Irish Rose”, 1910 (567: Edison Amberol)
- “The Preacher and the Bear”, 1913 (1560: Edison Blue Amberol)

- In all cases, the signal has simply been band-pass filtered between in the audible range of interest
  - No noise reduction, nor application of equalisation to match the recording’s original recording characteristics

UNIVERSITY OF Southampton
School of Engineering Sciences

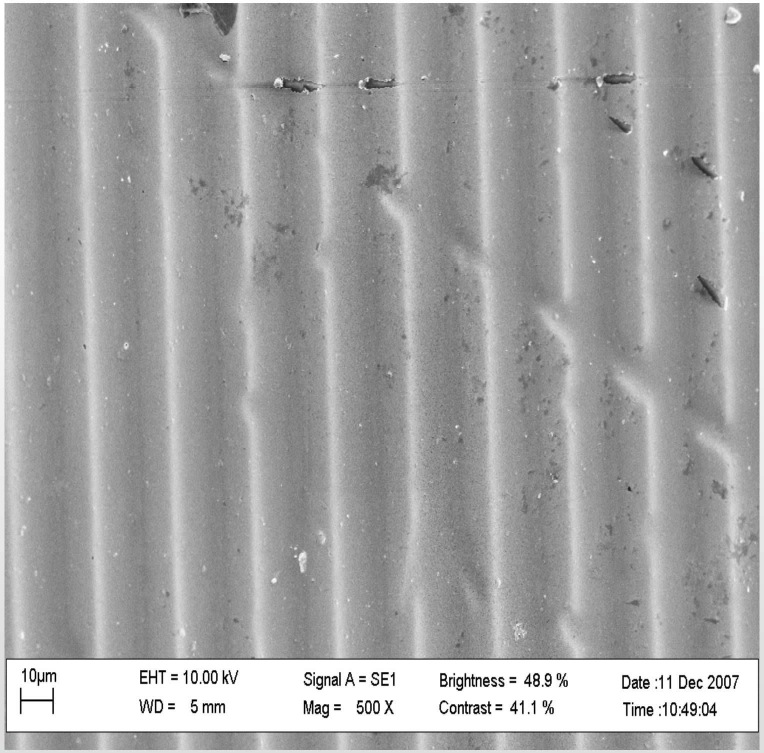
Understanding Sensor Limitations for inclined surfaces

Aims of Sensor Comparison Study

UNIVERSITY OF Southampton
School of Engineering Sciences

- Compare how systems interact with small scale samples with sloping surfaces. Recorded surfaces have typical wavelengths of 100µm by 40µm PV.
- Using sinusoidal reference samples with 25 and 8µm wavelengths and various PV dimensions.
- Investigate the limits of the white light system, as this has been identified as offering the best combination of scanning speed, angular tolerance and vertical resolution (10nm).
- Study data robustness during high speed (low precision) scanning. Typical scan rates of 25mm/sec, with 1kHz sensor rate.

- Comparison of Sensors and Systems
  - Con-focal white light sensor (WL)
  - Con-focal laser (CL)
  - Atomic force microscope (AFM)
  - White light interferometer (WLI)



Reference samples

- Four 25µm pitch sinusoidal artifacts
- Four 8µm pitch sinusoidal artifacts
- 8µm pitch rectangular.

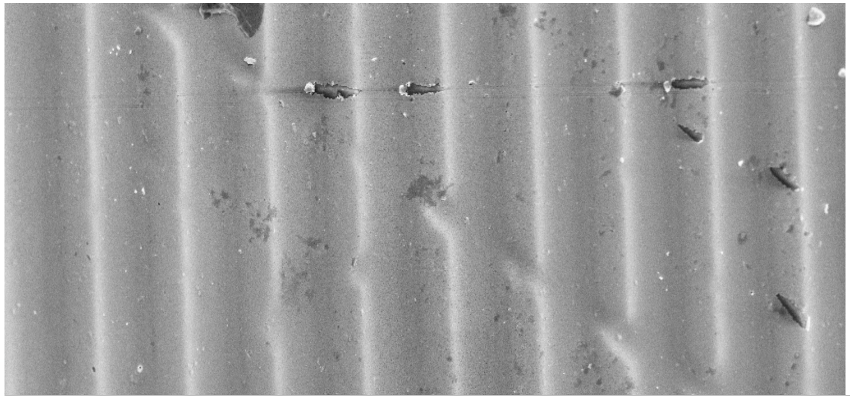
UNIVERSITY OF Southampton
School of Engineering Sciences

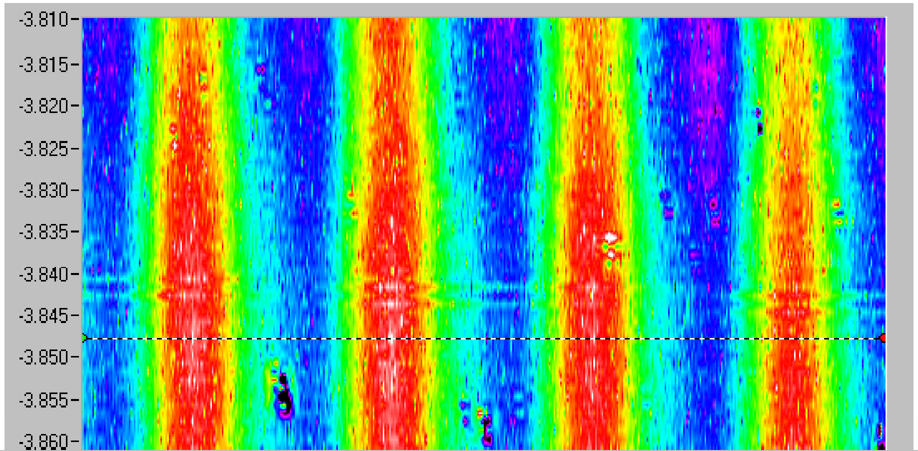
Period (μm)	Peak-to-valley amplitude (μm)	Maximum Gradient (°)
→ 25A	2.720	37.20
25B	0.654	5.30
25C	0.531	3.90
25D	0.134	1.10
8A	0.496	17.10
→ 8B	0.124	3.00
8C	0.068	1.50
8D	0.020	0.50

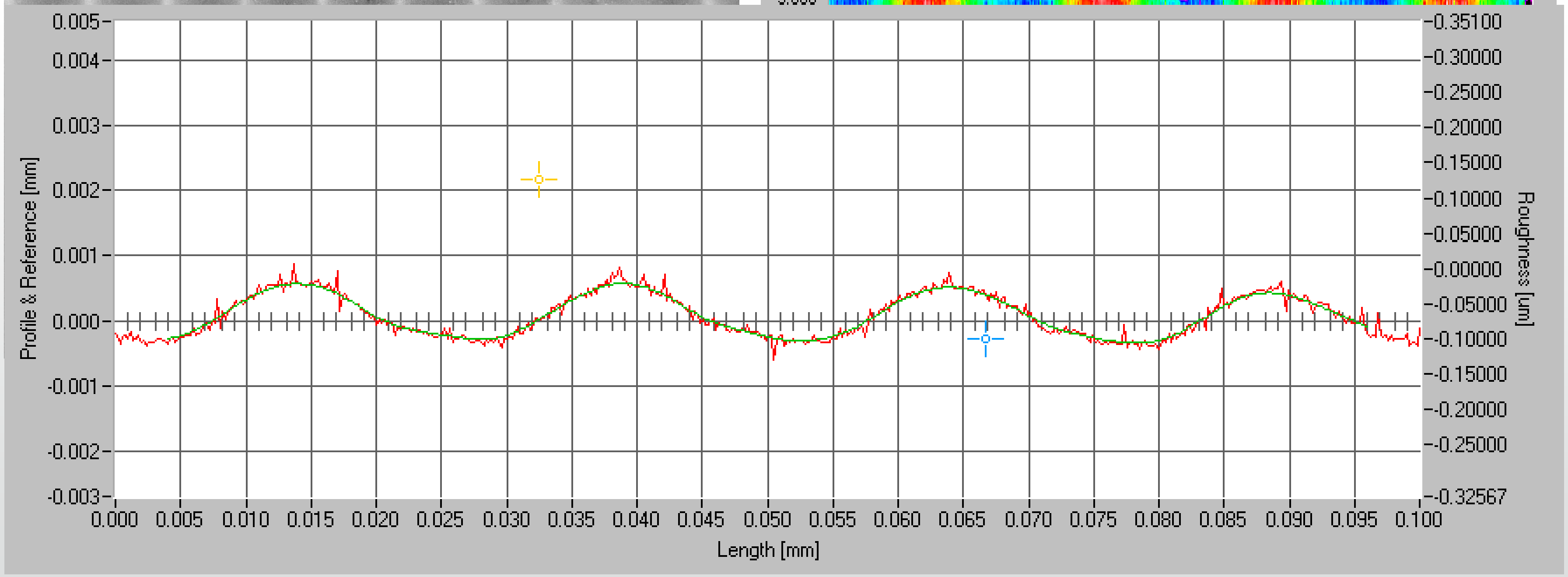
Specifications of the sinusoidal samples

SEM measurement of the 25µm sample C

UNIVERSITY OF Southampton
School of Engineering Sciences

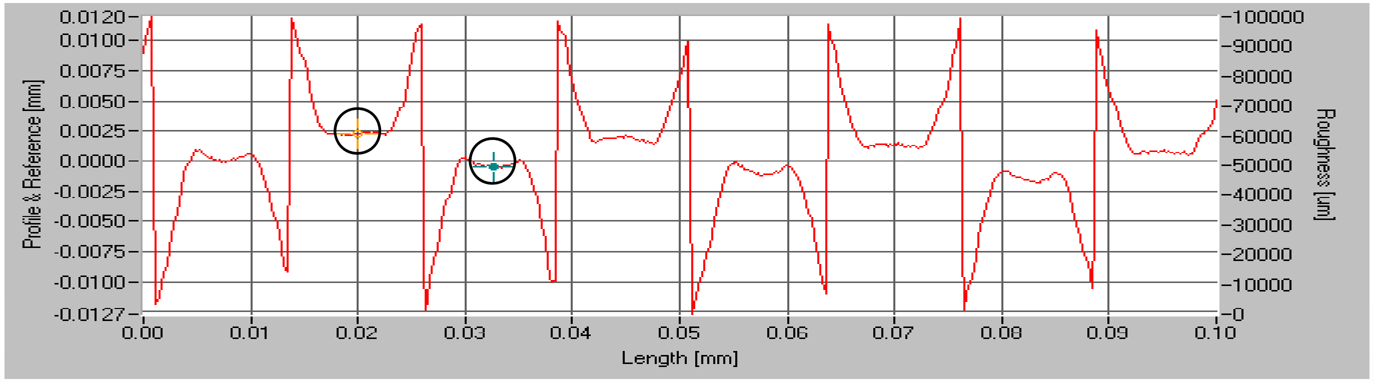






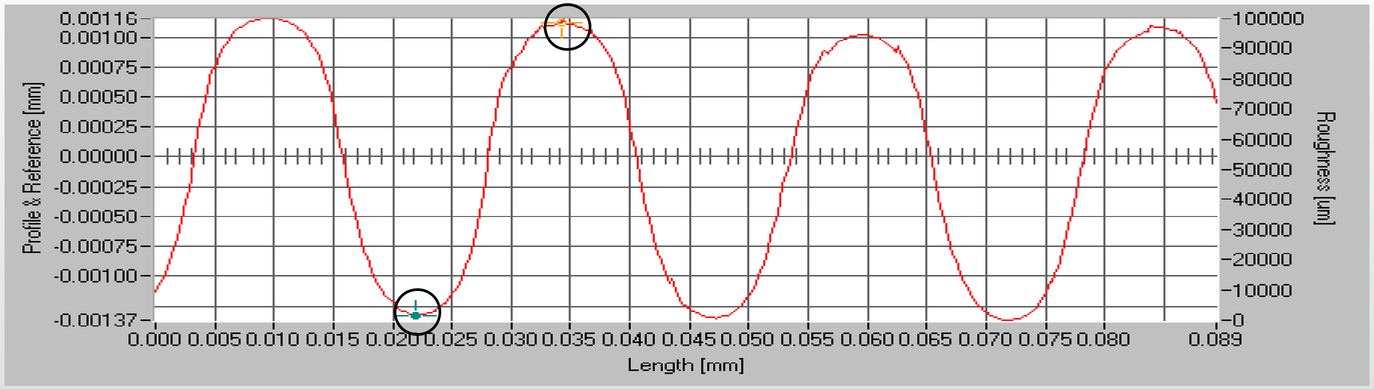
Measurements of 25A sinusoid of 25µm period, 2.72µm peak-to valley (PV) distance

- CL



501 × 101, 0.1mm × 0.1mm, 0.2µm grid spacing, low precision

- AFM



448 × 56, 0.09mm × 0.0125mm, 0.2µm grid spacing, contacting mode

Conclusions and Recommendations

- For the preservation of flat disc recorded surfaces the X,Y (horizontal) resolution is required to match the 10nm in vertically modulated surfaces.

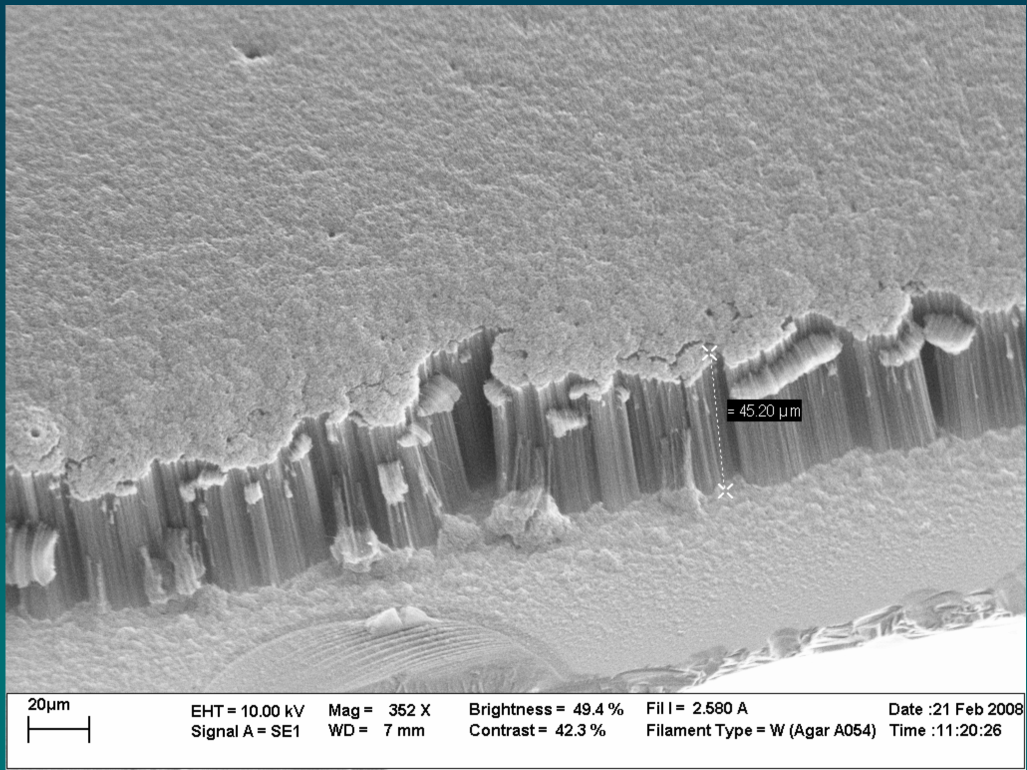
- It has been shown that the resolution required can be achieved using an inclined sensor, (with some loss of sensor resolution).

- Current research is focused on modelling expected data output and in the integration of multiple sensors with sensor angles of 45 degrees.

- Both Con-Focal Laser and Chromatic WL Sensor have been demonstrated as offering potential solutions.

UNIVERSITY OF Southampton
School of Engineering Sciences

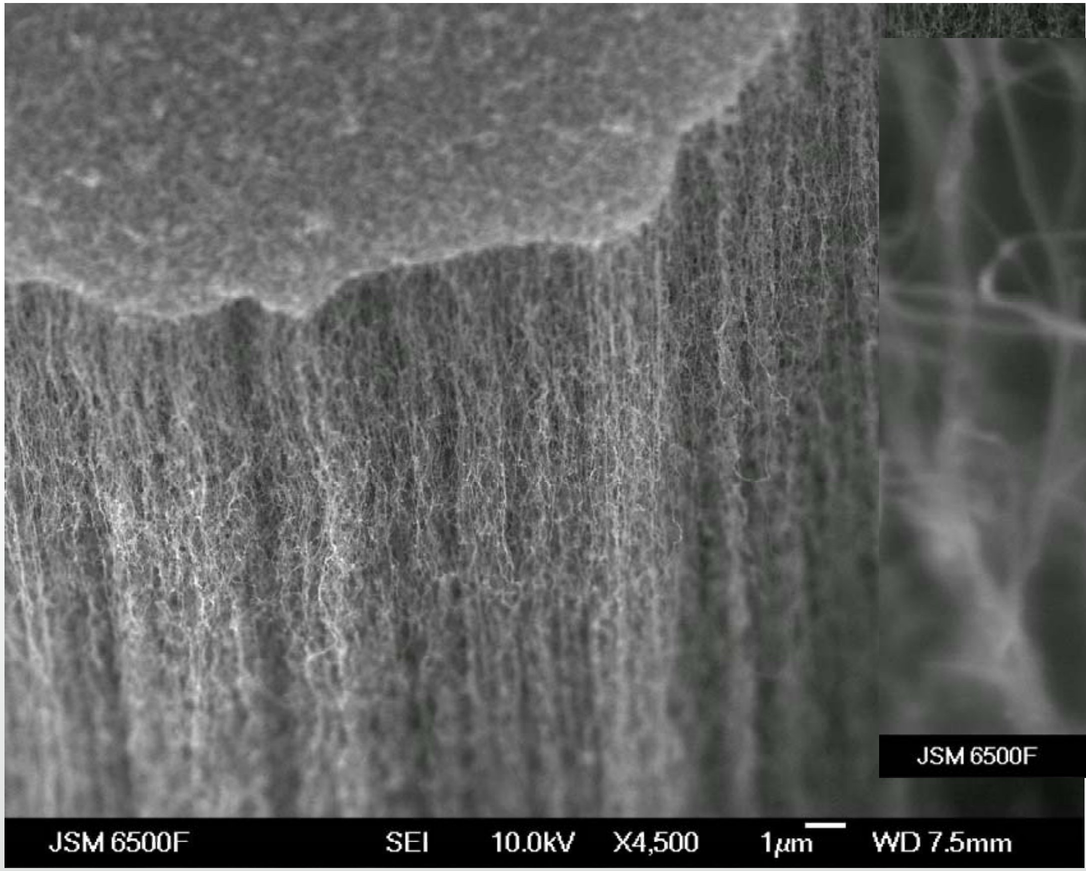
Multi-walled carbon nanotube surfaces.

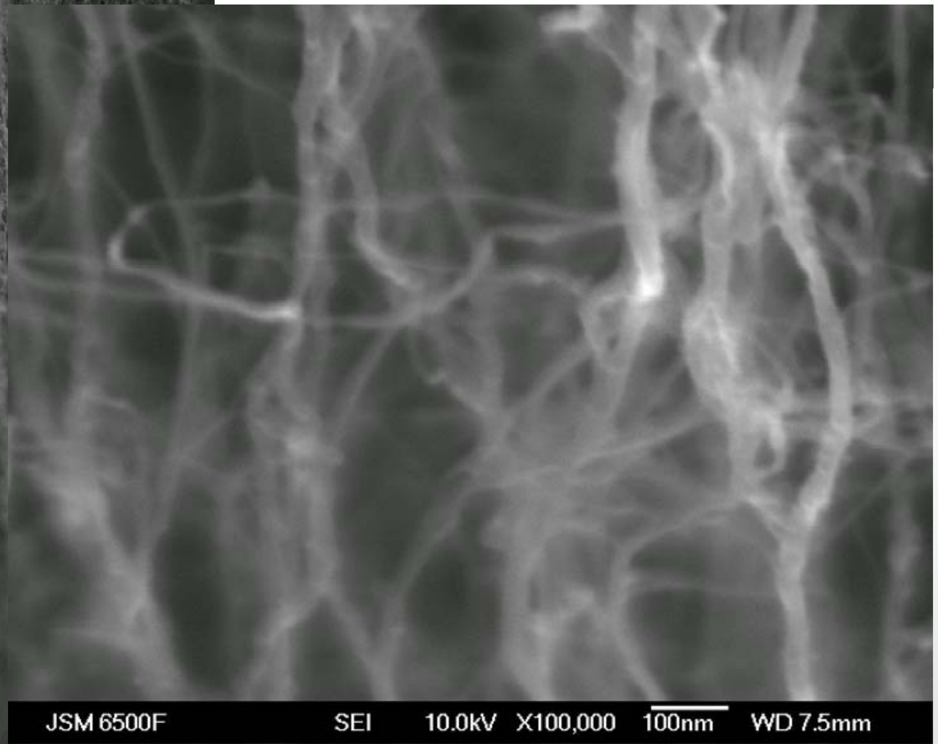


UNIVERSITY OF Southampton
School of Engineering Sciences

Papers in 2009-10

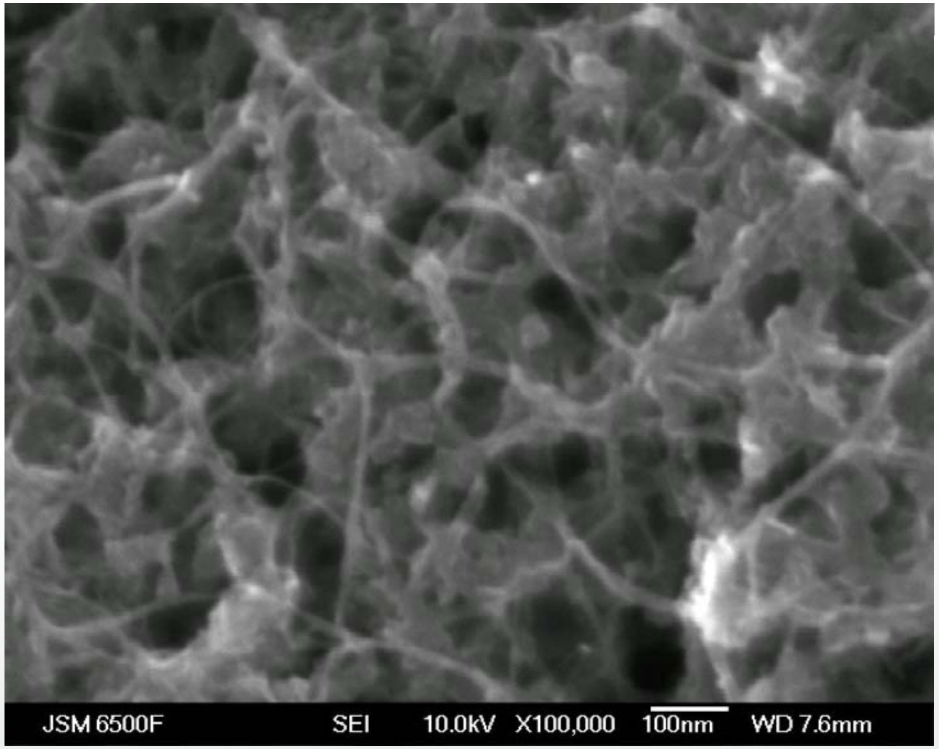
- Yunus, E.M., Spearing, S.M. and McBride, J.W (2009) The relationship between contact resistance and contact force on Au-coated carbon nanotube surfaces under low force conditions. *IEEE Transactions on Components and Packaging Technologies*, 32, (3), 650-657. (doi:10.1109/TCAPT.2009.2014964)
- McBride, J.W., Yunus, E.M. and Spearing, S.M. (2009) Gold coated carbon nanotube surfaces as low force electrical contacts for MEMS devices: part 1. In, *55th IEEE Holm Conference on Electrical Contacts, Vancouver, Canada 14 - 16 Sep 2009.* , 7pp, 278-284.
- Yunus, E.M., McBride, J.W. and Spearing, S.M. (2009) Improving the contact resistance at low force using gold coated carbon nanotube surfaces. *European Journal of Applied Physics* (In Press)

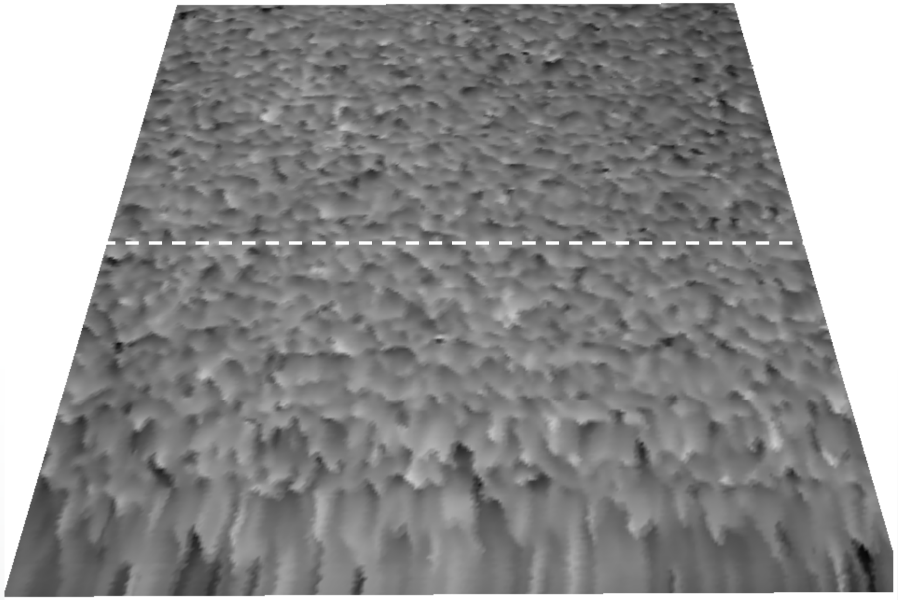

JSM 6500F
SEI
10.0kV
X4,500
1μm
WD 7.5mm

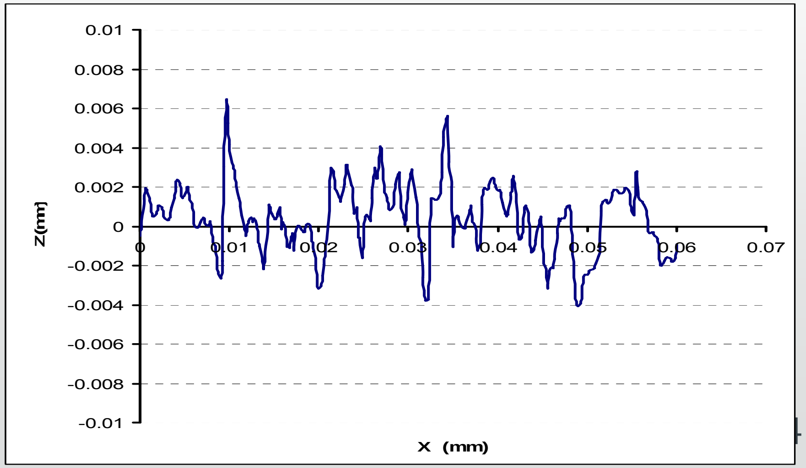

JSM 6500F
SEI
10.0kV
X100,000
100nm
WD 7.5mm

Top of CNT surface

UNIVERSITY OF Southampton
School of Engineering Sciences



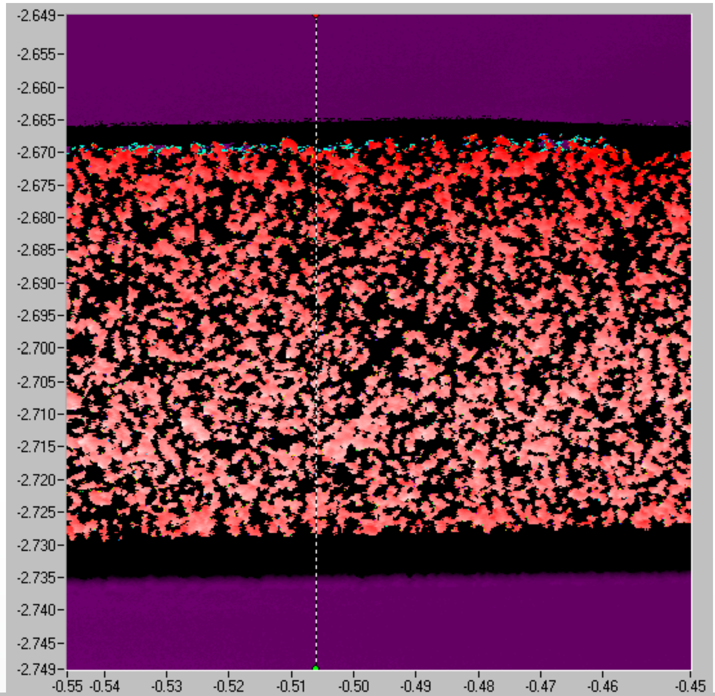




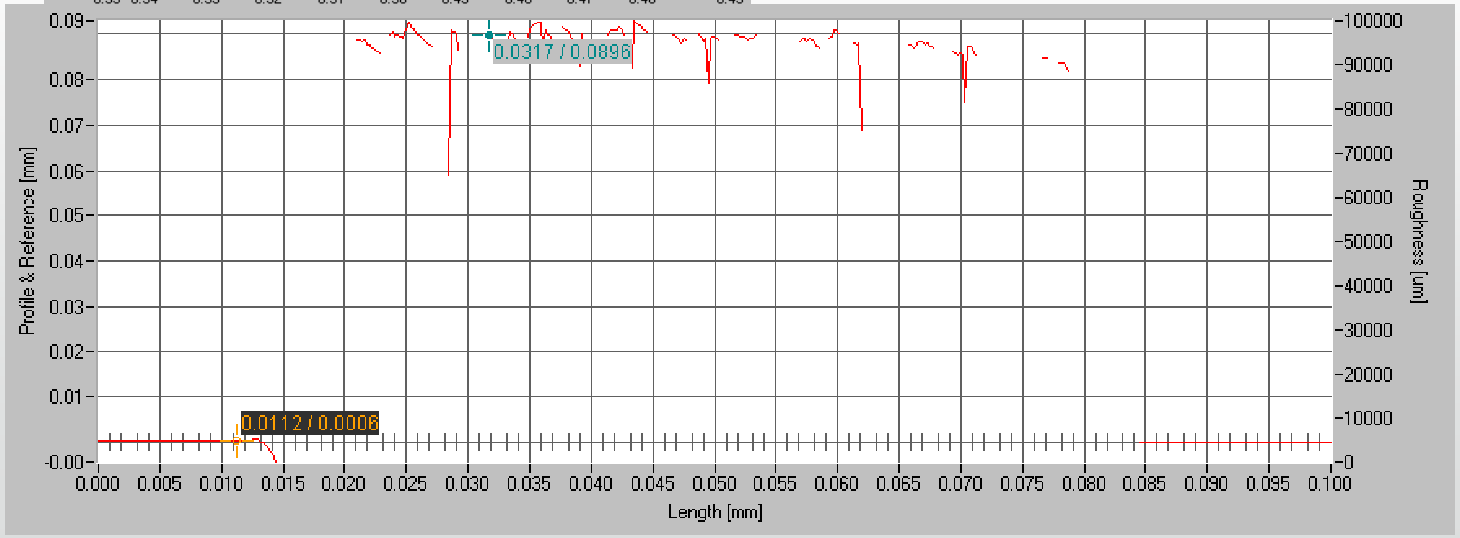
Con-focal Laser Scanned image of MWNT 301x301 (60μm x 60μm) using TaiCaan Technologies (Xyris 4000CL), showing 2D section of data (0.2μm grid)

70μm wide strip of CNT

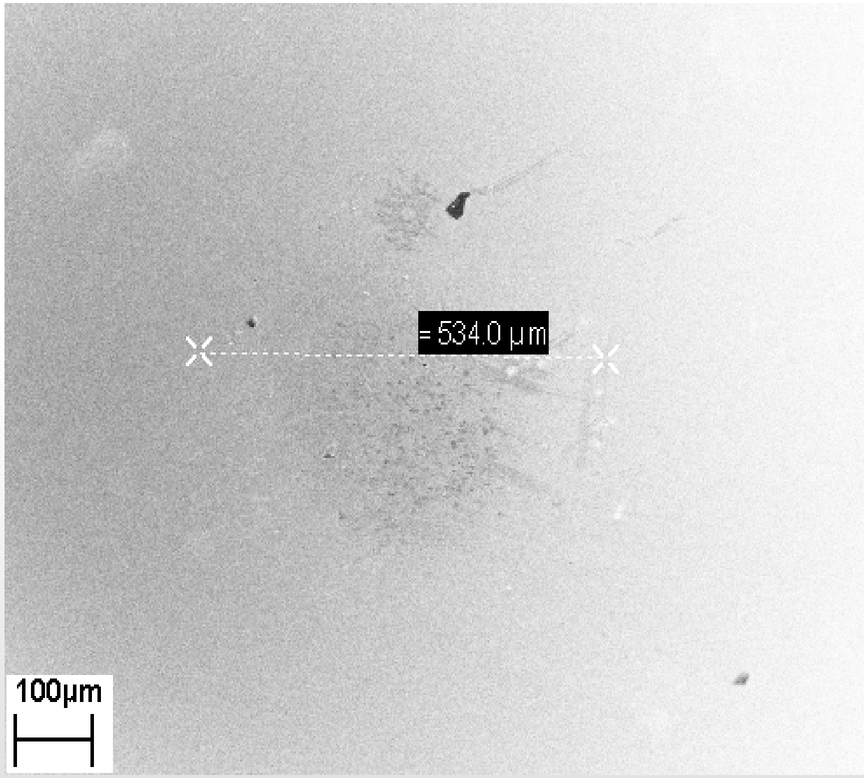
UNIVERSITY OF Southampton
School of Engineering Sciences



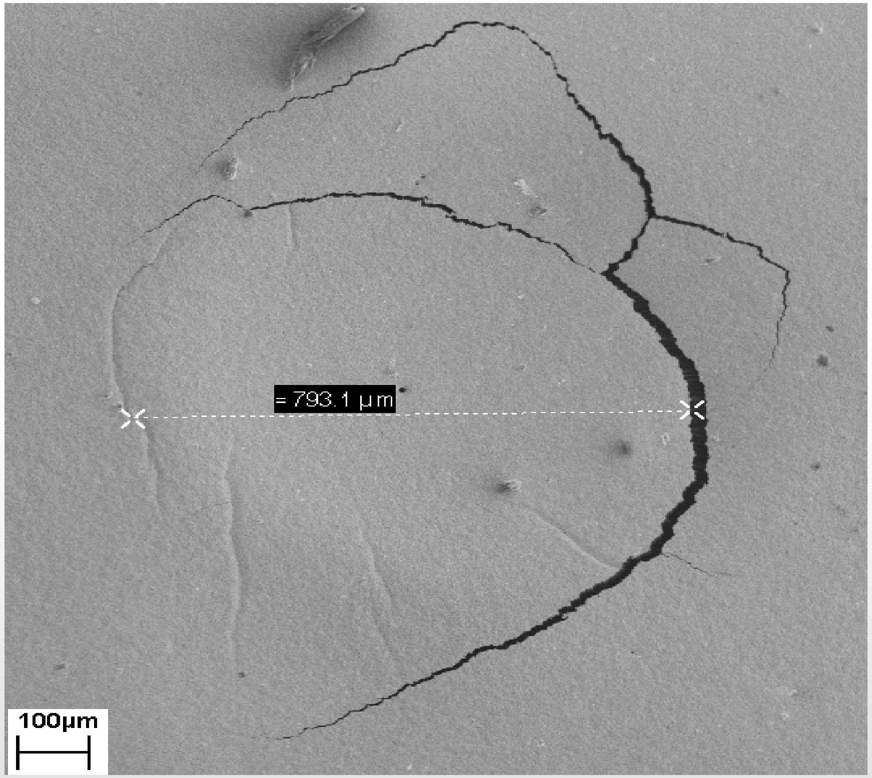
501x501data of 01.mm x0.1mm
0.2μm grid



Contact surface after 20 million cycles “mechanical test at 3mN



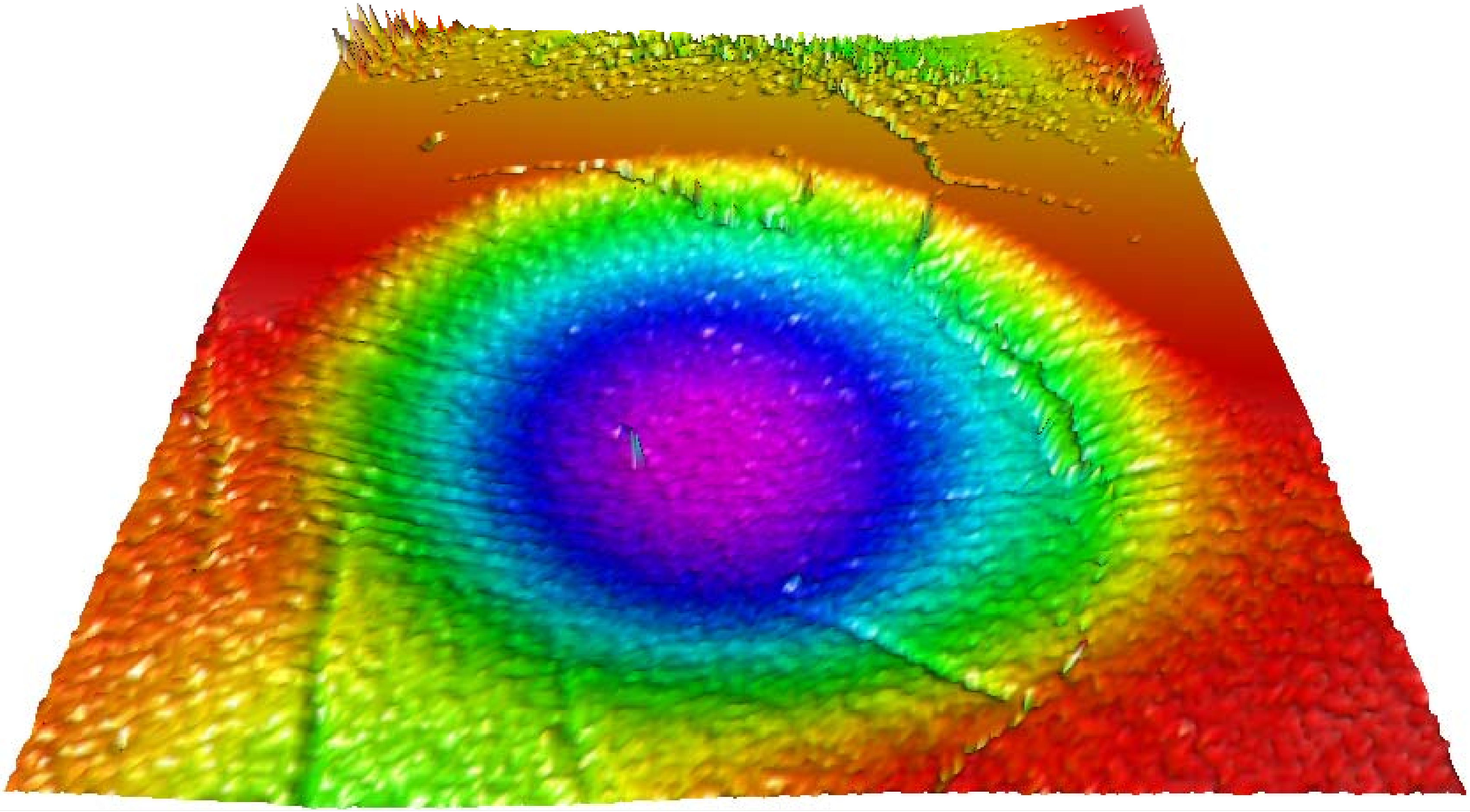
Au hemispherical probe after 20 million cycles



Au/MWCNT composites after 20 million cycles

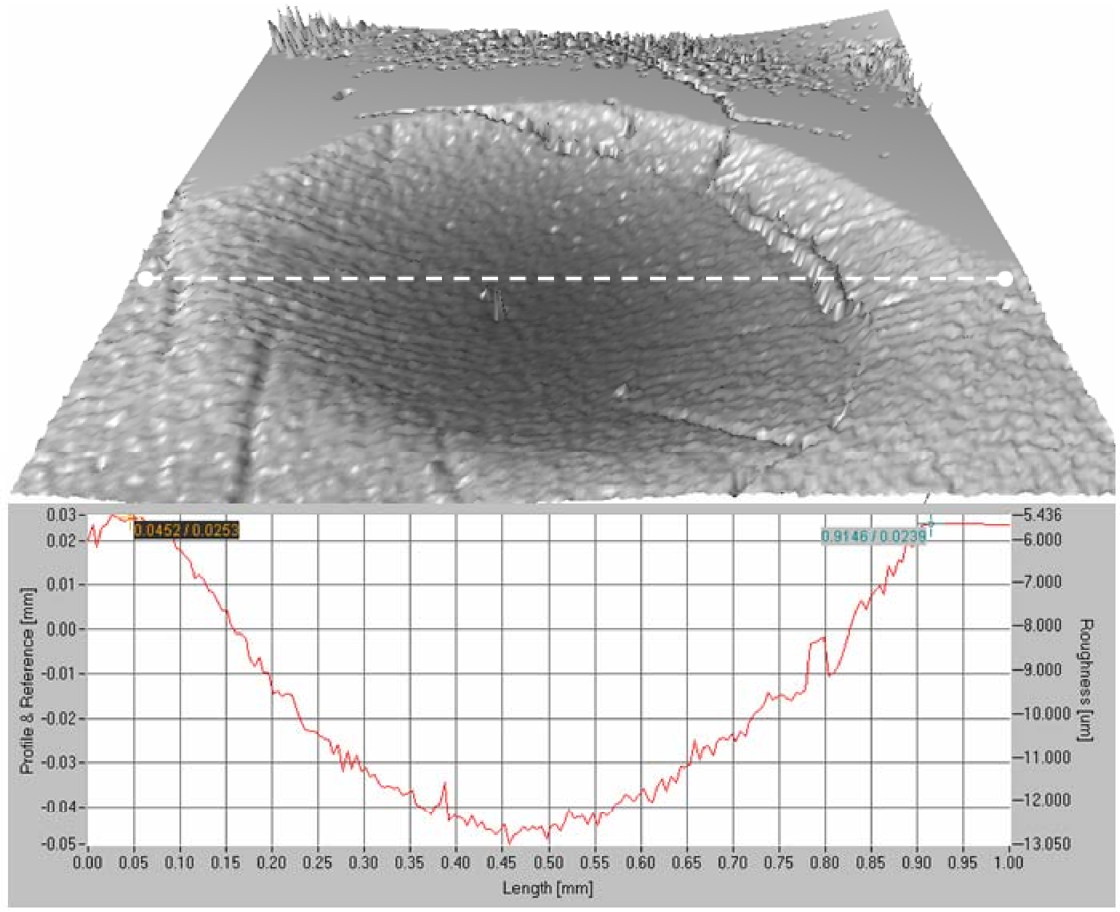
Image of Contact Region

UNIVERSITY OF Southampton
School of Engineering Sciences



Scanned image of contact surface after 20 million cycles

UNIVERSITY OF Southampton
School of Engineering Sciences



Scanned image of Au/MWCNT composite contact pair(201x201/1mm x 1mm) using TaiCaan Xyris 4000CL

UNIVERSITY OF Southampton
School of Engineering Sciences

New Directions

- New project into the characterisation of structured surfaces using an array of optical sensors, and using data fusion to create the full surface map.
- New project on the characterisation of CNT surfaces.
  - Contact mechanics
  - Electrical Contact Characterisation.
- New project on building a MEMs devices platform.

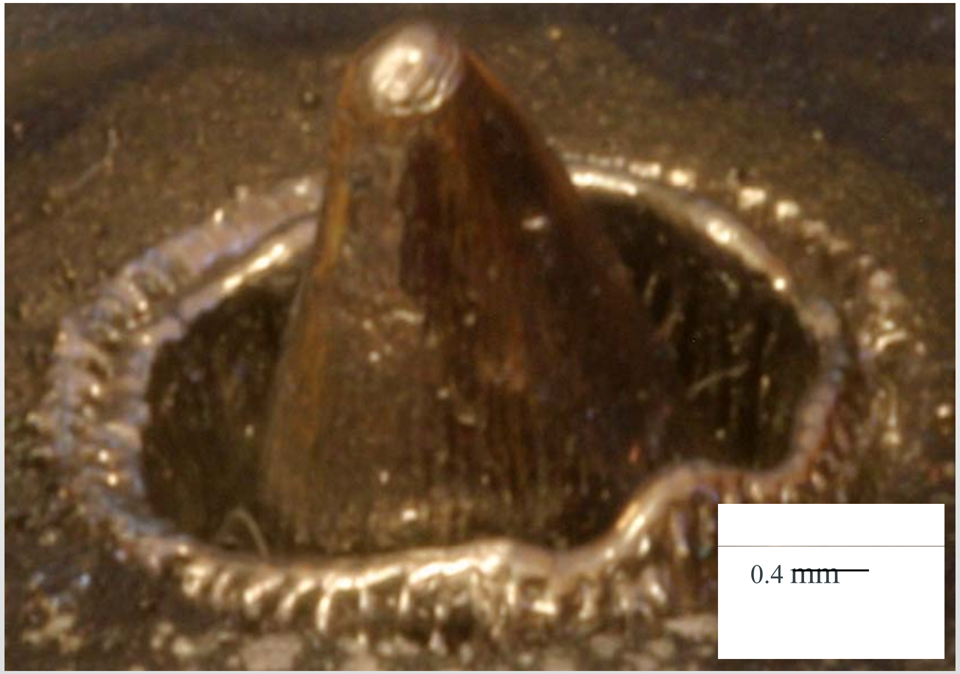
UNIVERSITY OF Southampton
School of Engineering Sciences

Current Research on Structured Surfaces

Applications

UNIVERSITY OF Southampton
School of Engineering Sciences

- Heat exchangers,
- Medical devices,
- Fixtures
- Fluid Control



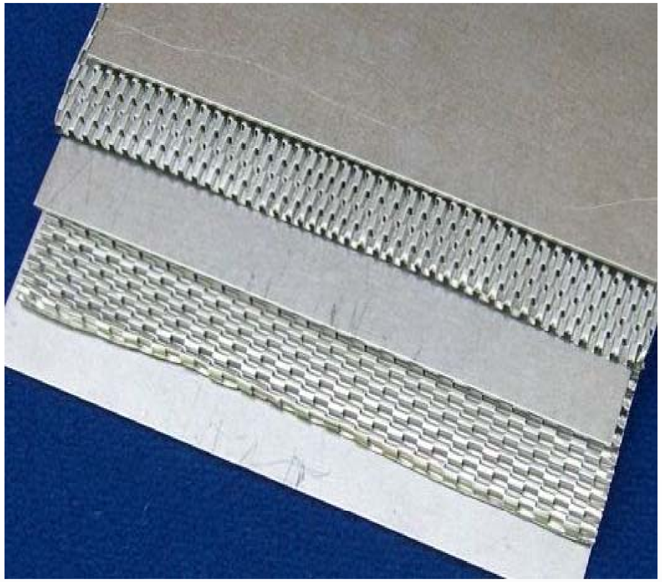


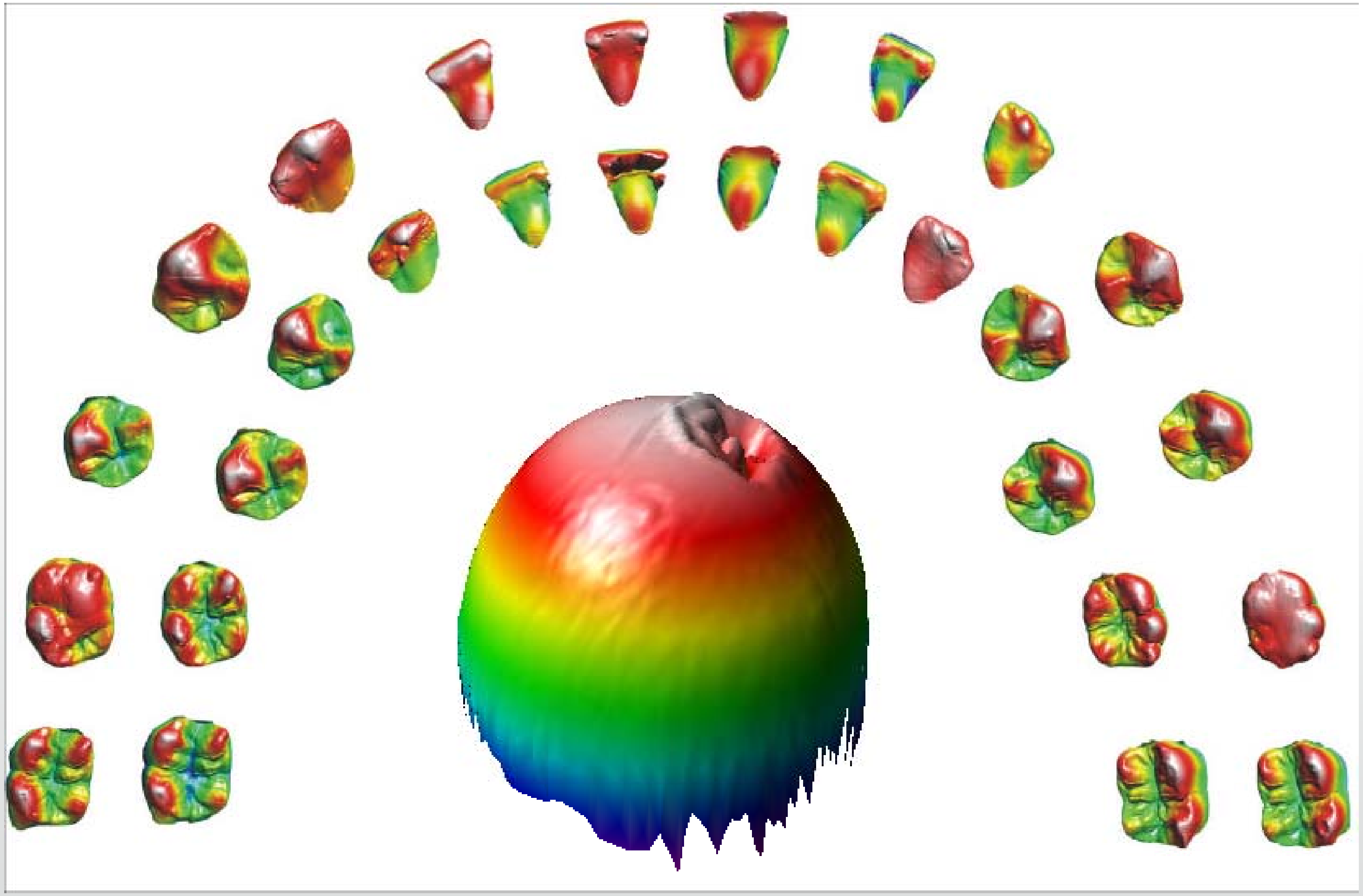
Plate fin heat exchanger

Hip joint implant

Wear of Free Form Surface.

UNIVERSITY OF Southampton
School of Engineering Sciences

- In collaboration with the metrology company TaiCaan Technologies Ltd.

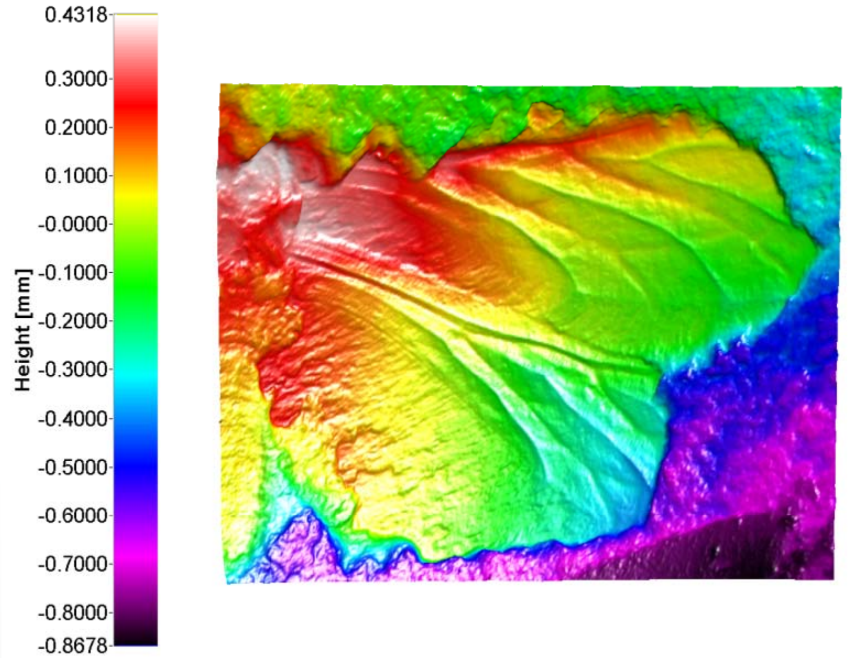


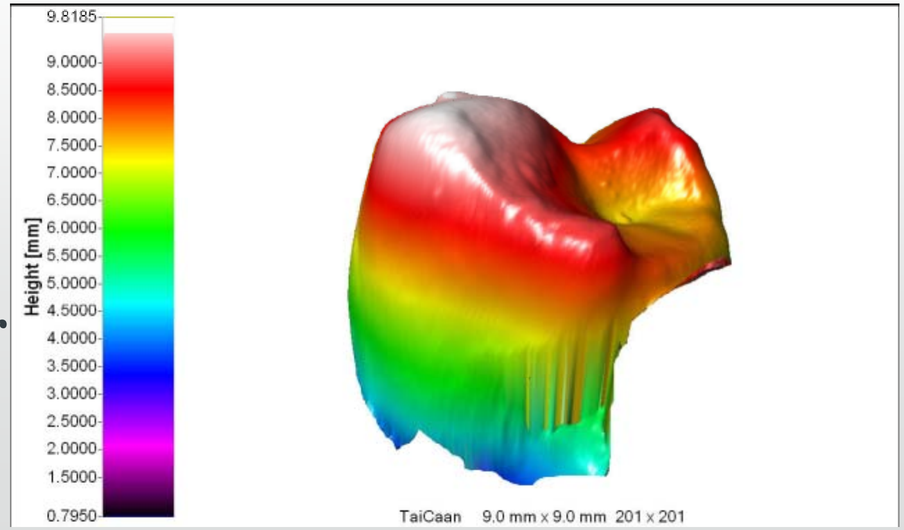
Free Form Surface Research

UNIVERSITY OF Southampton
School of Engineering Sciences

- Collaborations with
- TaiCaan Technologies Ltd.
  - www.taicaan.com

  Micro-Materials Ltd.
- Universities
  - Cardiff University
  - Kings College London
  - Imperial College London
  - University of Montpellier
  - University of Rennes.

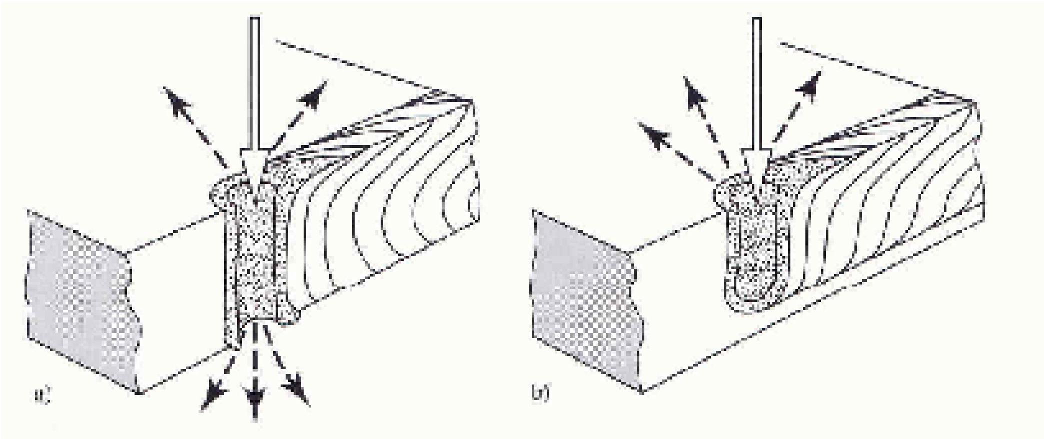


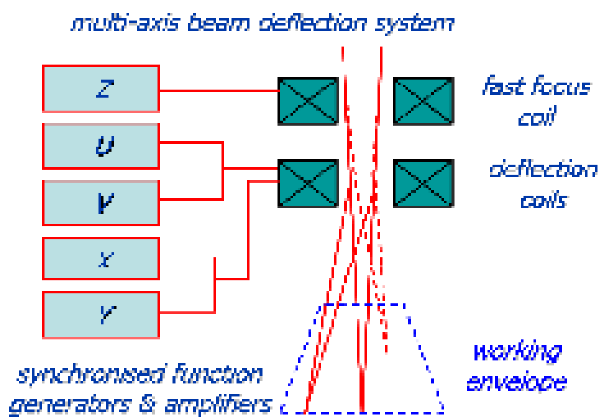


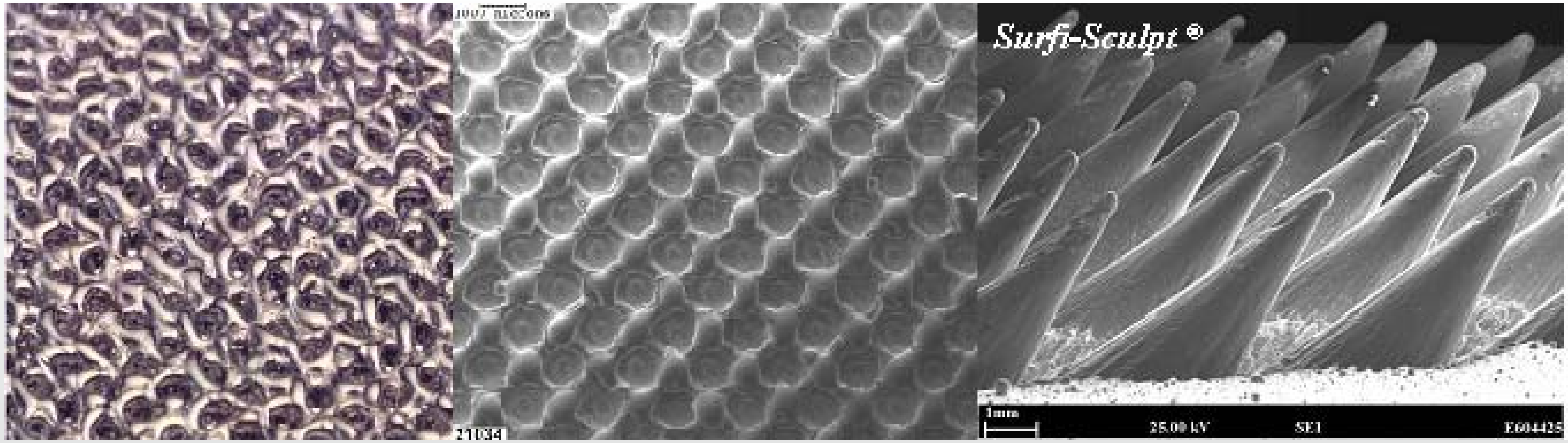
New Research

- Data Fusion from multiple con-focal sensors.
- The properties if laser triangulation
- Electron-Beam Sculpted Surfaces
- The application of micro-computed tomography.
  - Lipscomb, I.P., Weaver, P.M., Swingler, J. and McBride, J.W. (2008) Micro-computer tomography: an aid in the investigation of structural changes in lead zirconate titanate ceramics after temperature-humidity bias testing. *Journal of Electroceramics*, 4pp. (doi:10.1007/s10832-008-9537-8)
  - Lipscombe, I.P., Weaver, P.M., Swingler, J. and McBride, J.W. (2009) The effect of relative humidity, temperature and electrical field on leakage currents in piezo-ceramic actuators under dc bias. *Sensors and Actuators A: Physical*, 151, (2), 179-186. (doi:10.1016/j.sna.2009.01.017)

Electron Beam Sculpted Surfaces



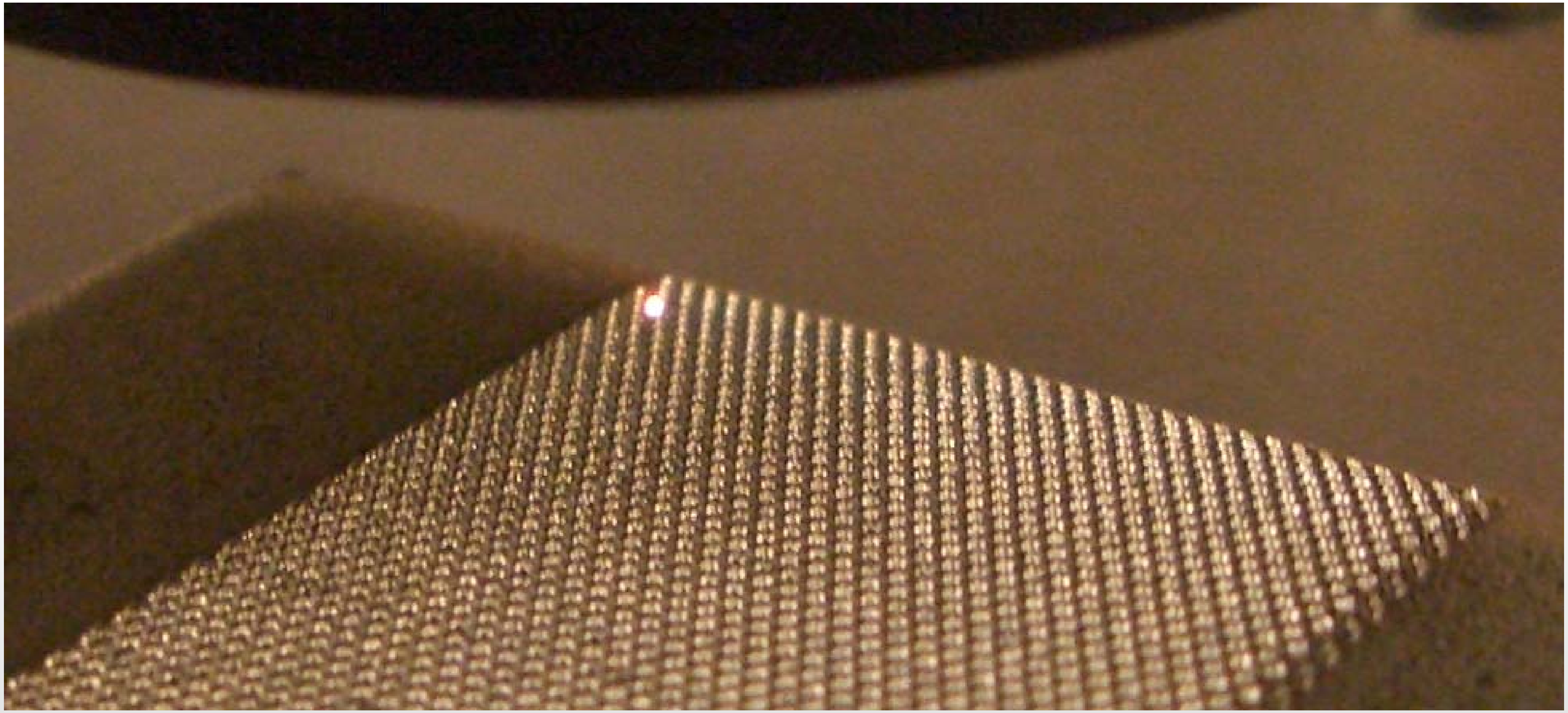




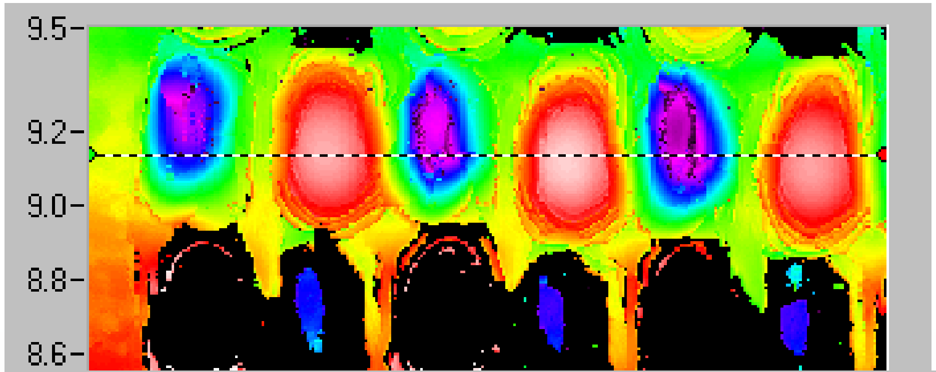
Ref. RAPID MATERIALS PROCESSING AND SURFACE SCULPTING USING ELECTRON BEAM AND LASER PROCESSES, by B.G.I Dance TWI Cambridge UK

UNIVERSITY OF Southampton
School of Engineering Sciences

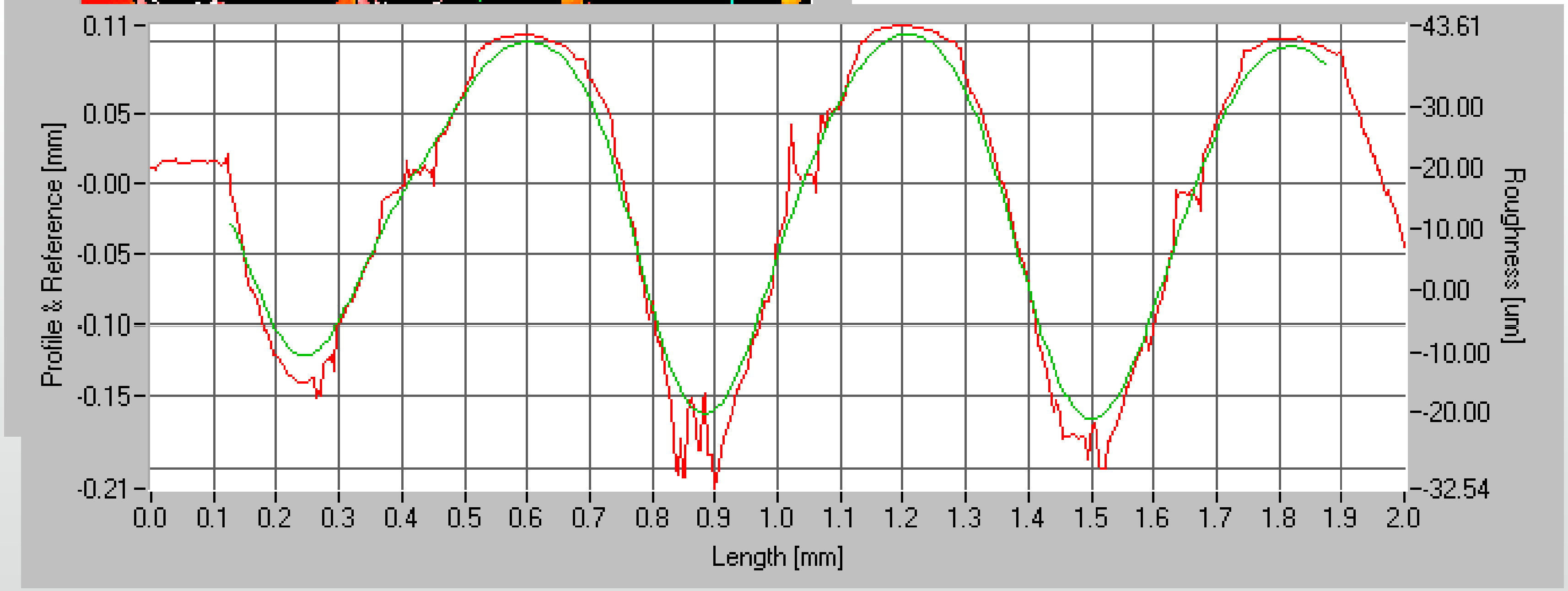
Surface Measured Using WL system



WL surface without data stitching

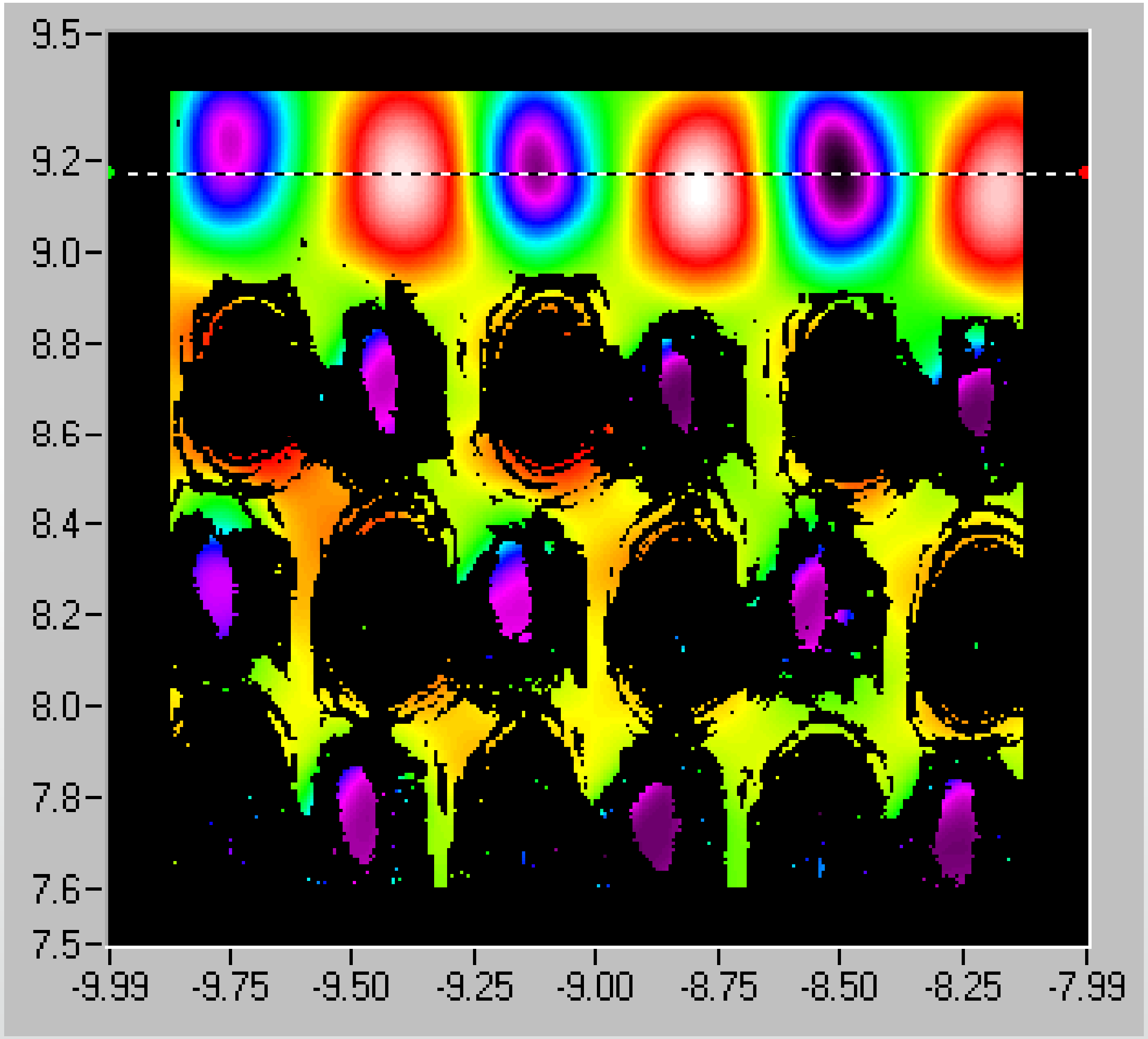


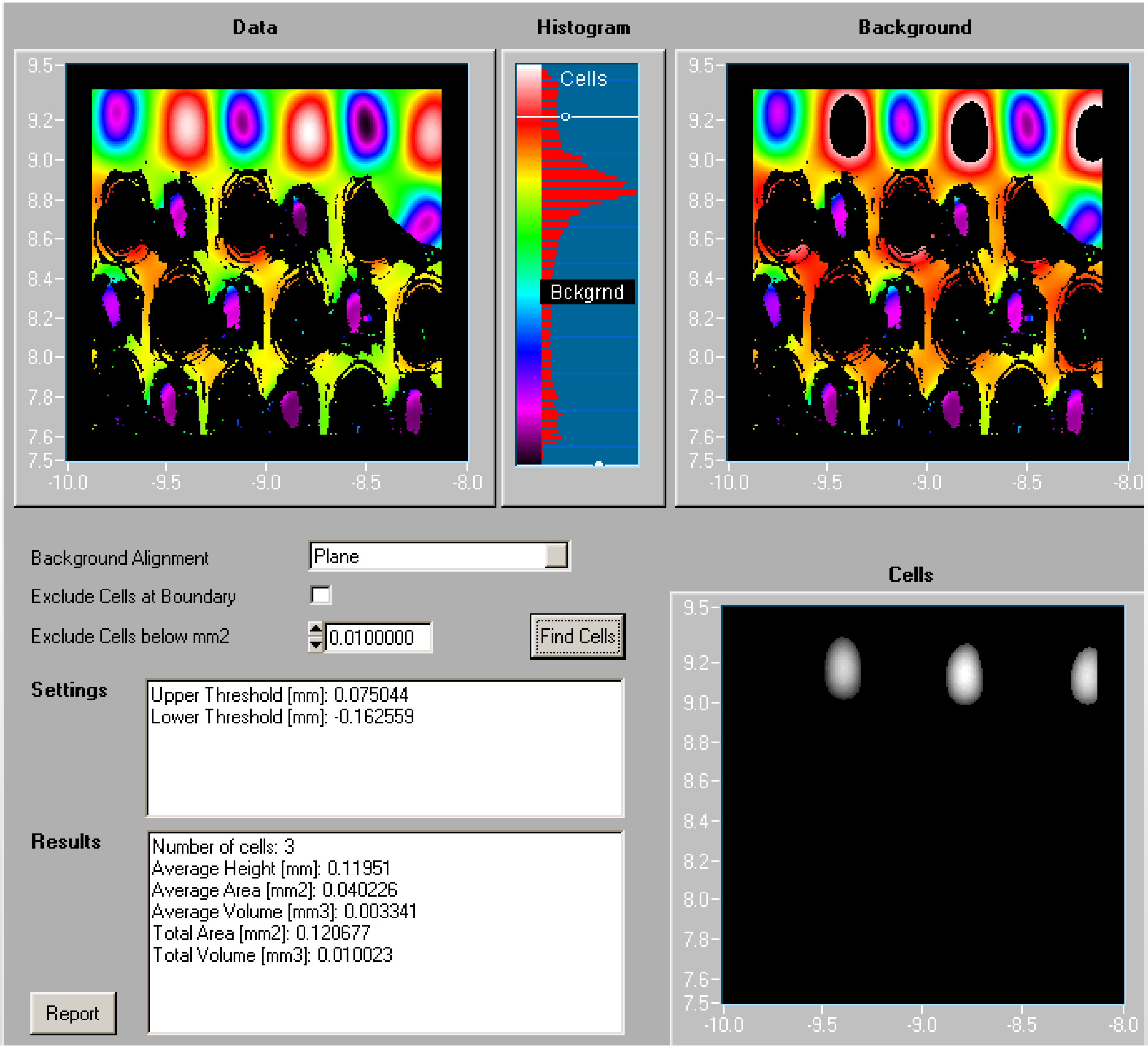
0.25mm gausian filtered surface



3D waviness filter using 0.25mm 3D gausian filter

UNIVERSITY OF Southampton
School of Engineering Sciences




Data
Histogram
Background
Cells
Bckgrnd
Background Alignment
Plane
Exclude Cells at Boundary
Exclude Cells below mm2
0.0100000
Find Cells
Settings
Upper Threshold [mm]: 0.075044
Lower Threshold [mm]: -0.162559
Results
Number of cells: 3
Average Height [mm]: 0.11951
Average Area [mm2]: 0.040226
Average Volume [mm3]: 0.003341
Total Area [mm2]: 0.120677
Total Volume [mm3]: 0.010023
Report
Cells

University of Southampton
School of Engineering Sciences

Surface Wear Analysis

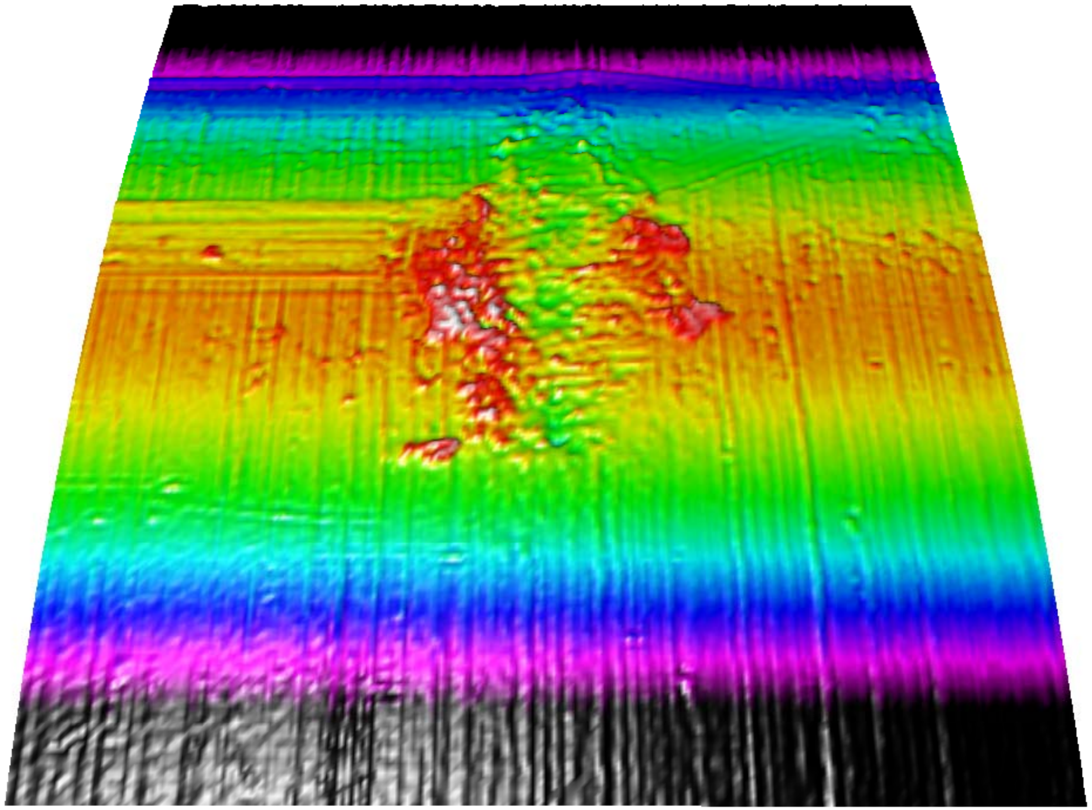
UNIVERSITY OF Southampton
School of Engineering Sciences

Selected refs

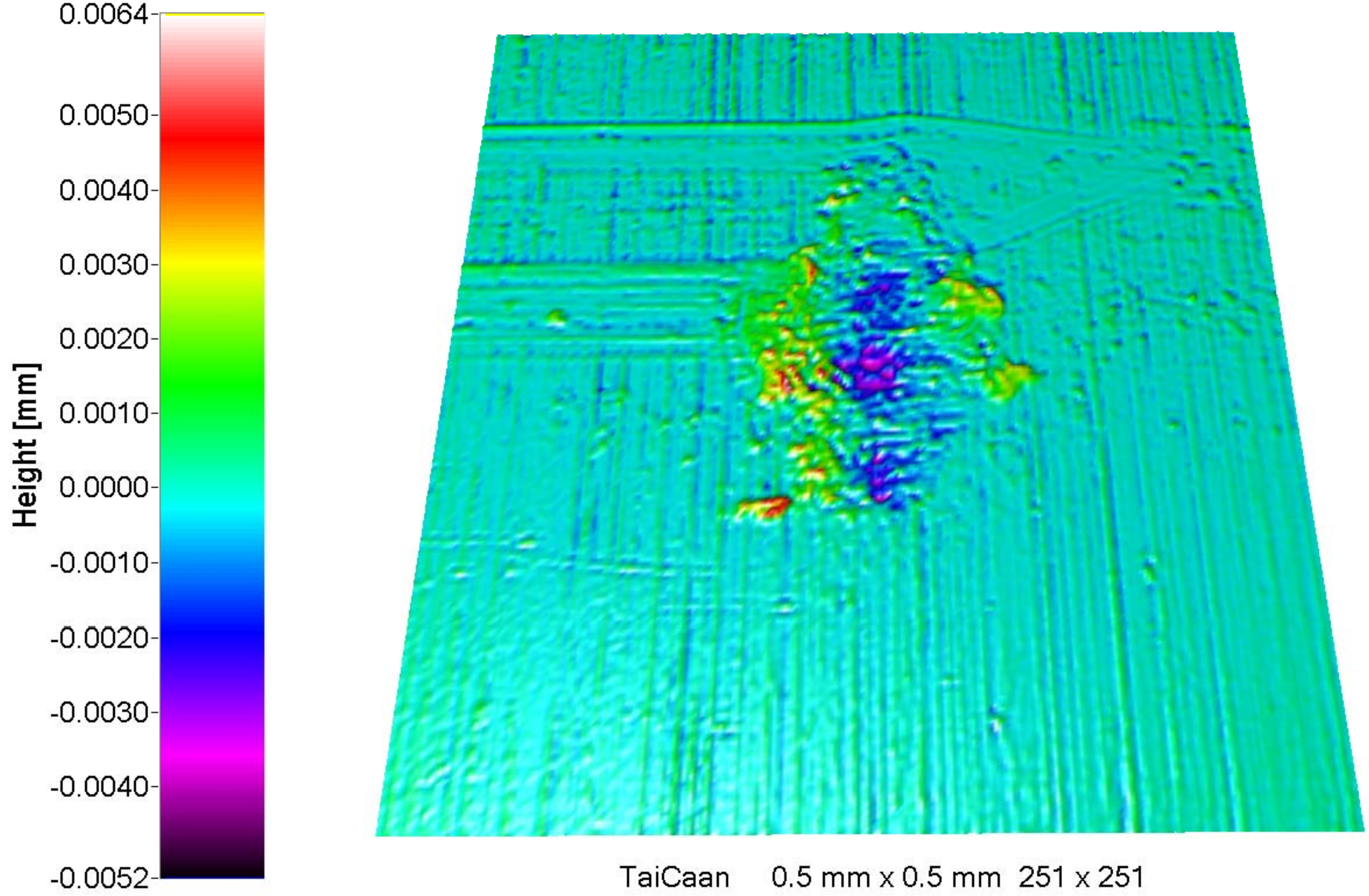
- McBride, J.W. and Cross, K.J. (2008) The evaluation of wear in the fretting of electrical contact surfaces. In, *Fretting Fatigue and Wear - Real-Life Solutions, Nottingham, UK 23 Sep 2008.* , 4pp.
- McBride, J.W. (2008) The relationship between surface wear and contact resistance during the fretting of in-vivo electrical contacts. *IEEE Transactions on Components and Packaging Technologies*, 31, (3), 592-600. (doi:10.1109/TCAPT.2008.2001162)

UNIVERSITY OF Southampton
School of Engineering Sciences

Fretting Wear Study Cylindrical Connector Surfaces



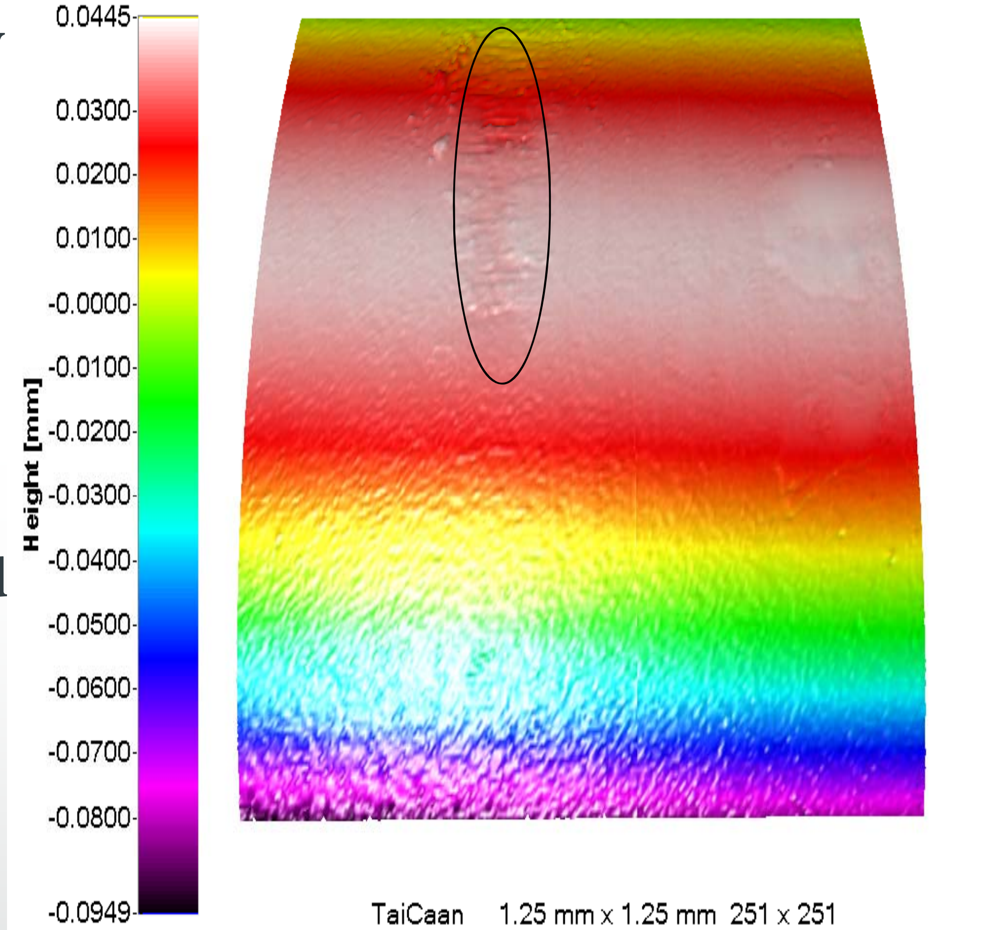
Removal of Cylindrical Form



Fretting Wear Studies

UNIVERSITY OF Southampton
School of Engineering Sciences

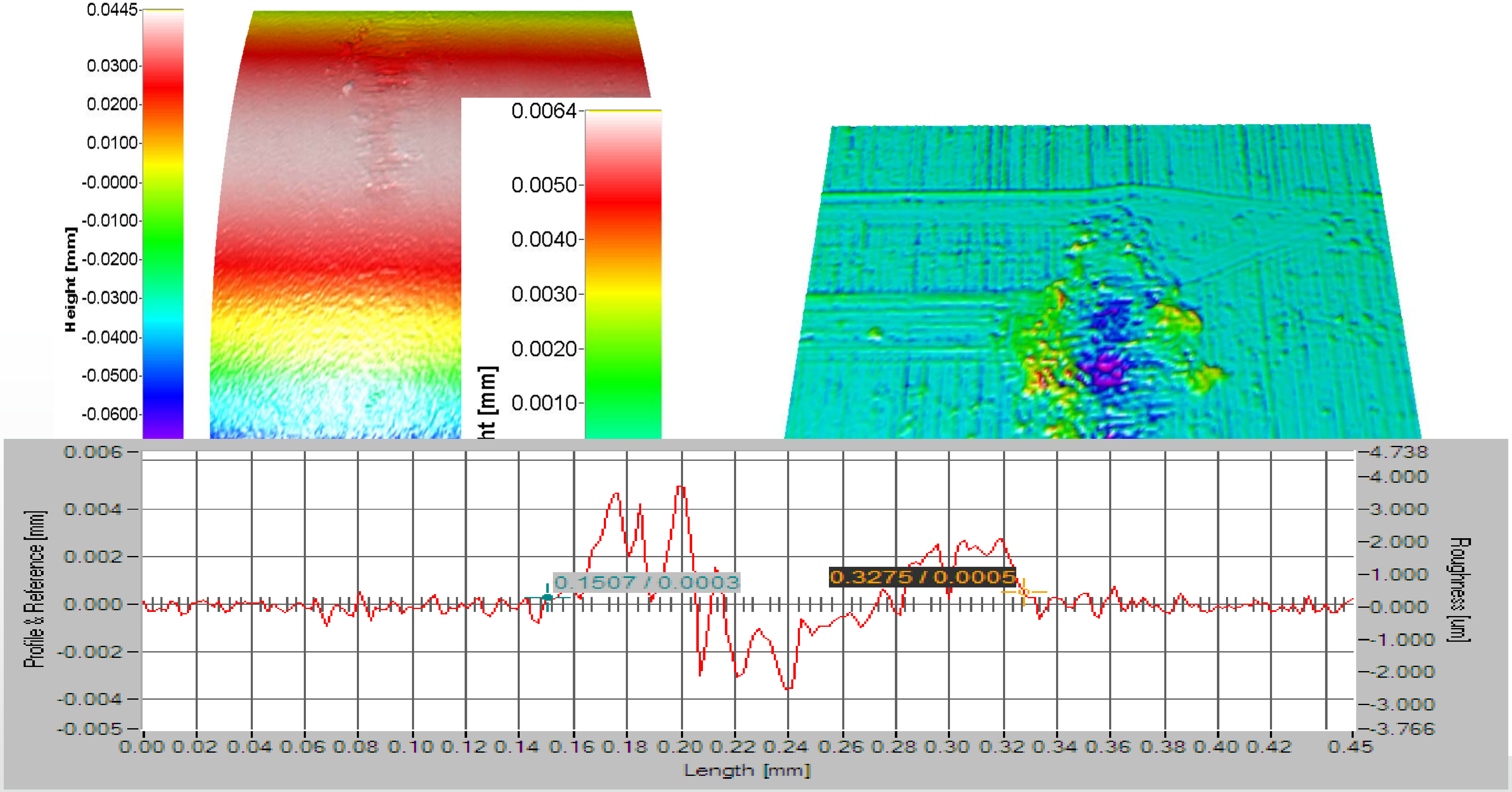
- Advances in 3D surface Metrology allow the accurate evaluation of surface wear.
- However there are a number of potential errors that need to be understood.
- The key issue is how to define a datum surface when the measured has 3D form, for example a cylinder connector surface, or a hemispherical contact.



McBride, J.W. (2008) The relationship between surface wear and contact resistance during the fretting of in-vivo electrical contacts. *IEEE Transactions on Components and Packaging Technologies*, 30pp.

The Evaluation of Wear

UNIVERSITY OF Southampton
School of Engineering Sciences



The Evaluation of Wear

UNIVERSITY OF Southampton
School of Engineering Sciences

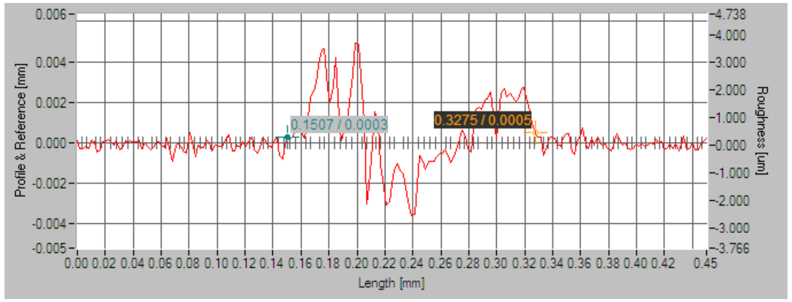
- The important question here is: should the form removal method be applied before the wear analysis?
- Method A Form removal applied to the wear region.
- Method B Wear region removed before form removal.

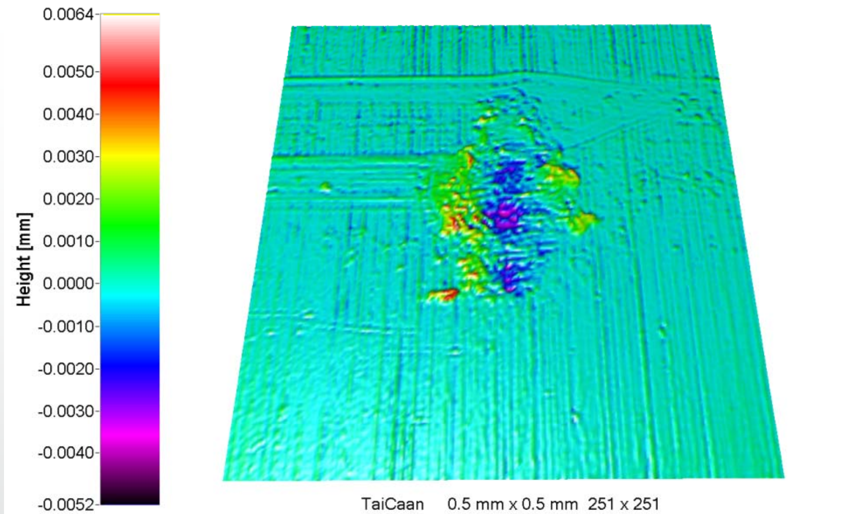
	Volume below the datum surface, after form removal, (mm^3)	Volume above the datum surface, after form removal. (mm^3)
Method A	15.3×10^{-5}	10.2×10^{-5}
Method B	16.3×10^{-5}	6.46×10^{-5}

UNIVERSITY OF Southampton
School of Engineering Sciences

Wear Analysis

- Overall length of wear track.176µm
- Inner wear track length72µm
- Maximum wear depth 3.8µm
- Maximum wear height 5.2µm
- Volume below datum 1.79x10-5
- Volume above datum 1.40x10-5





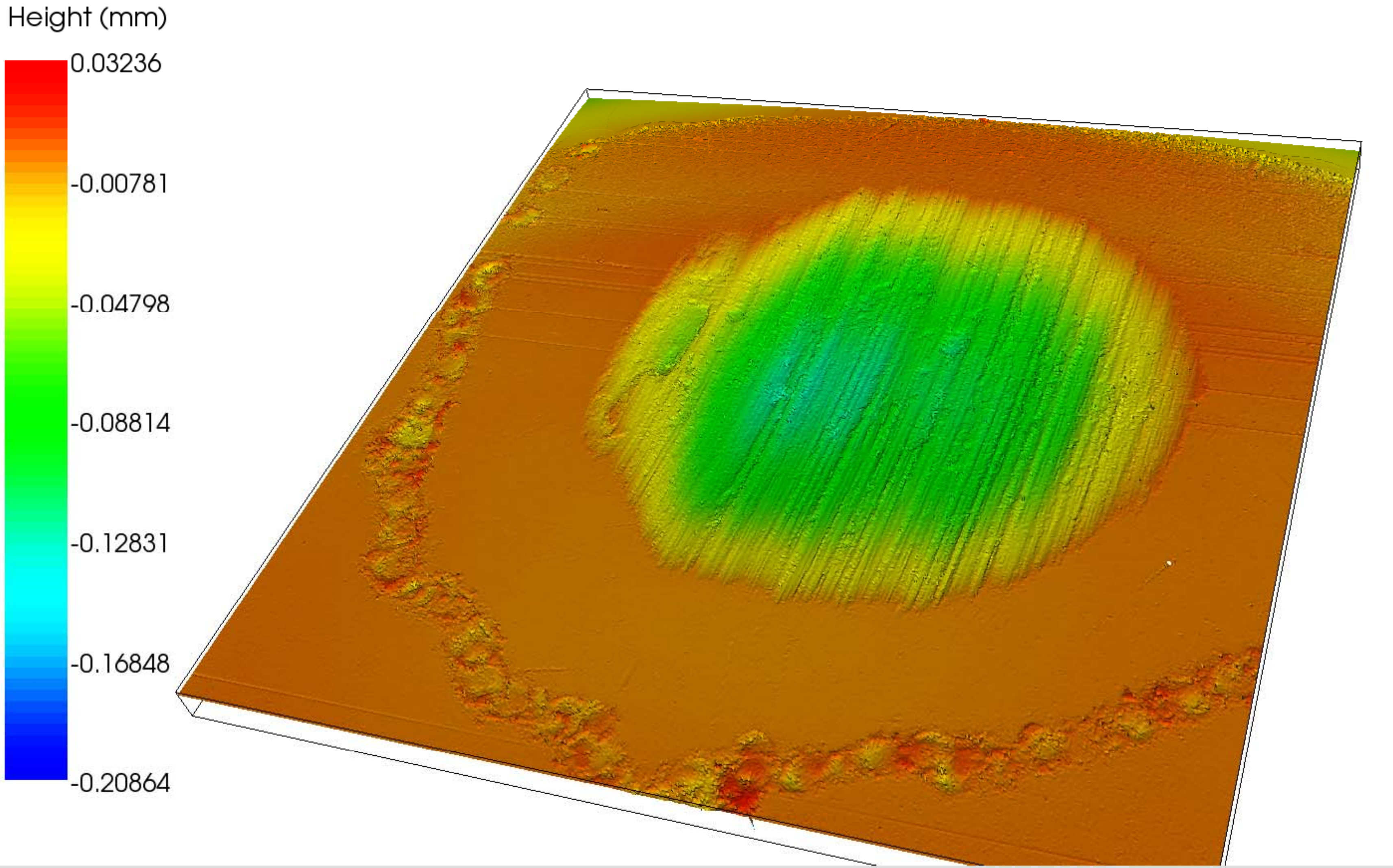
UNIVERSITY OF Southampton
School of Engineering Sciences

The New (2009) data viewer

- Sample from a commercial tribometer

UNIVERSITY OF Southampton
School of Engineering Sciences

New 3D Data Viewer 2009



Conclusion

- There are a large number of surface characterisation requirements
- Increasing importance of large scale data sets with submicron resolutions in all axes
- Applications not discussed include fluid flow interactions. Tribological applications, thermal and electrical conductivity applications.

UNIVERSITY OF Southampton
School of Engineering Sciences

Please see.

E.prints@soton.ac.uk

for copy of slides