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MANUFACTURING METROLOGY TEAM

Case studies in X-ray computed tomography surface texture measurement

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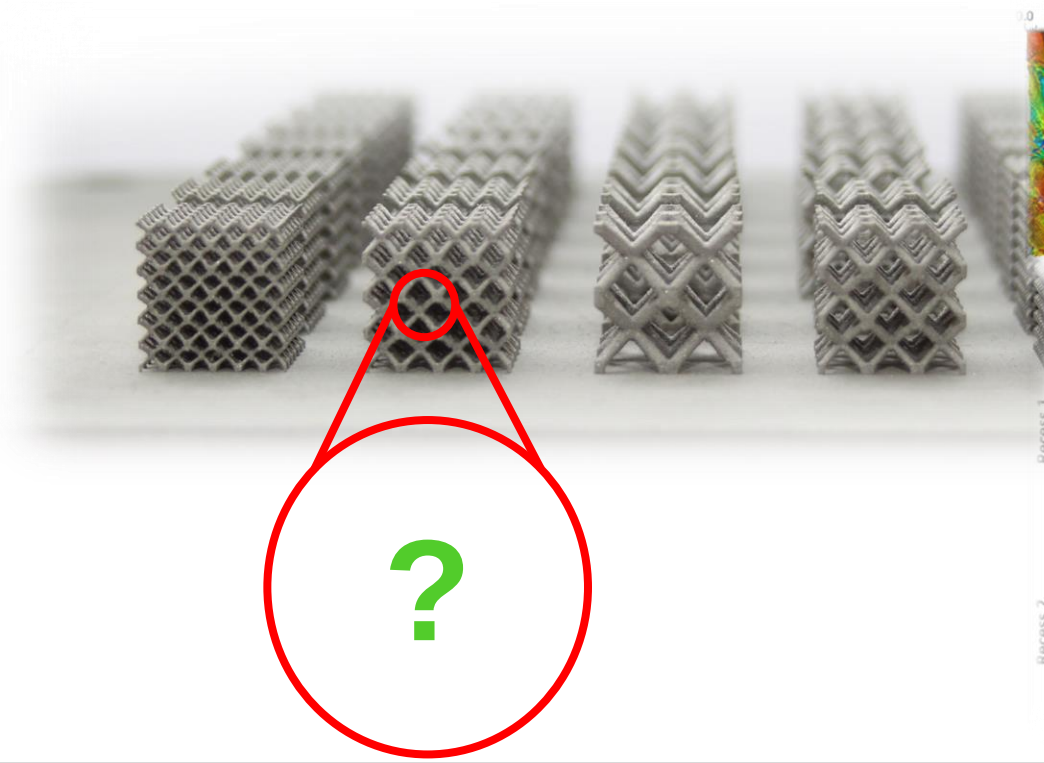
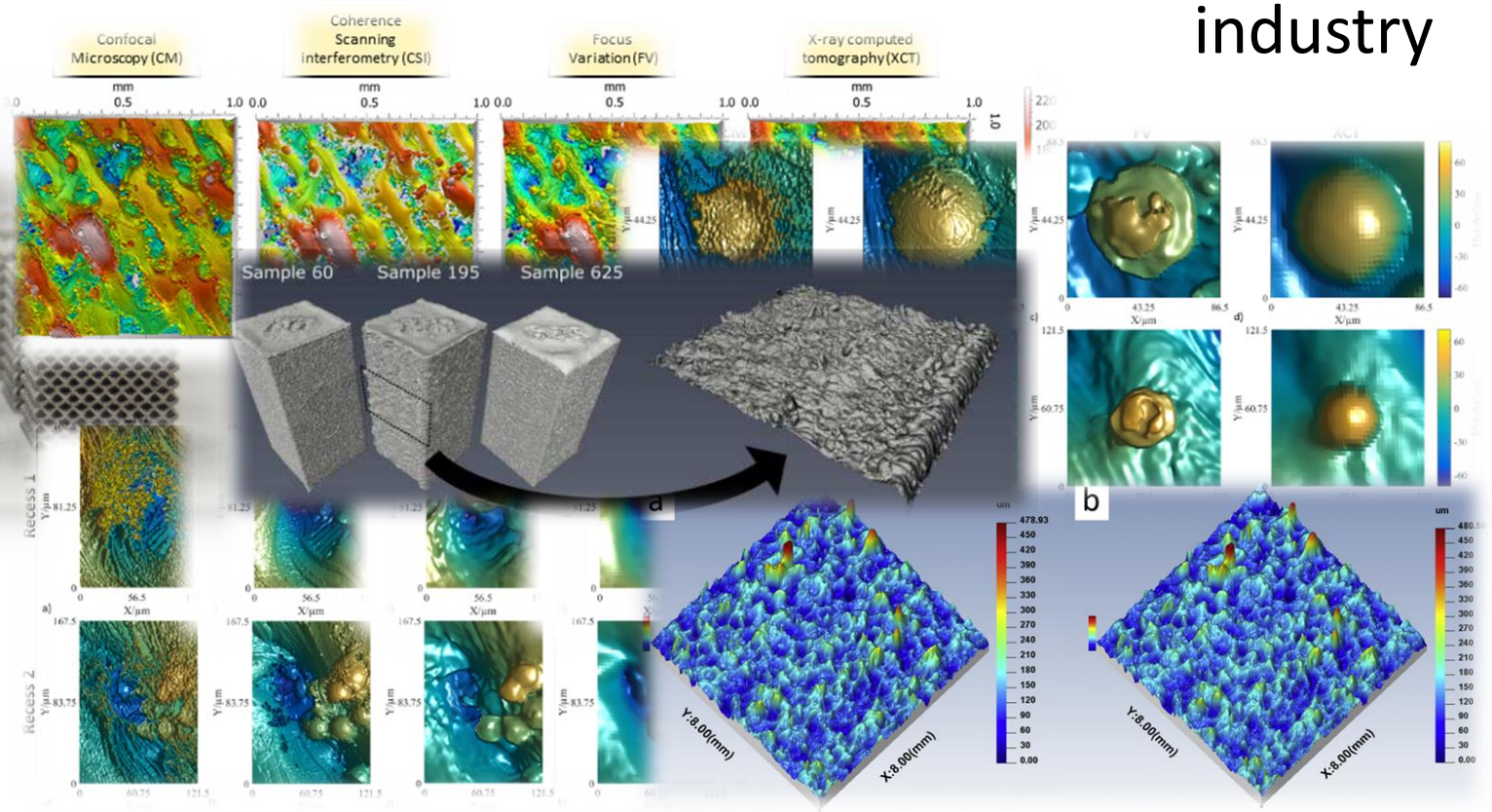
Introduction

Inaccessible surface measurement: now possible…

Until recently, measurement of internal and difficult-to-access surfaces was considered impossible

But recent advances have changed this thinking, and now people are measuring surfaces using XCT in research and industry

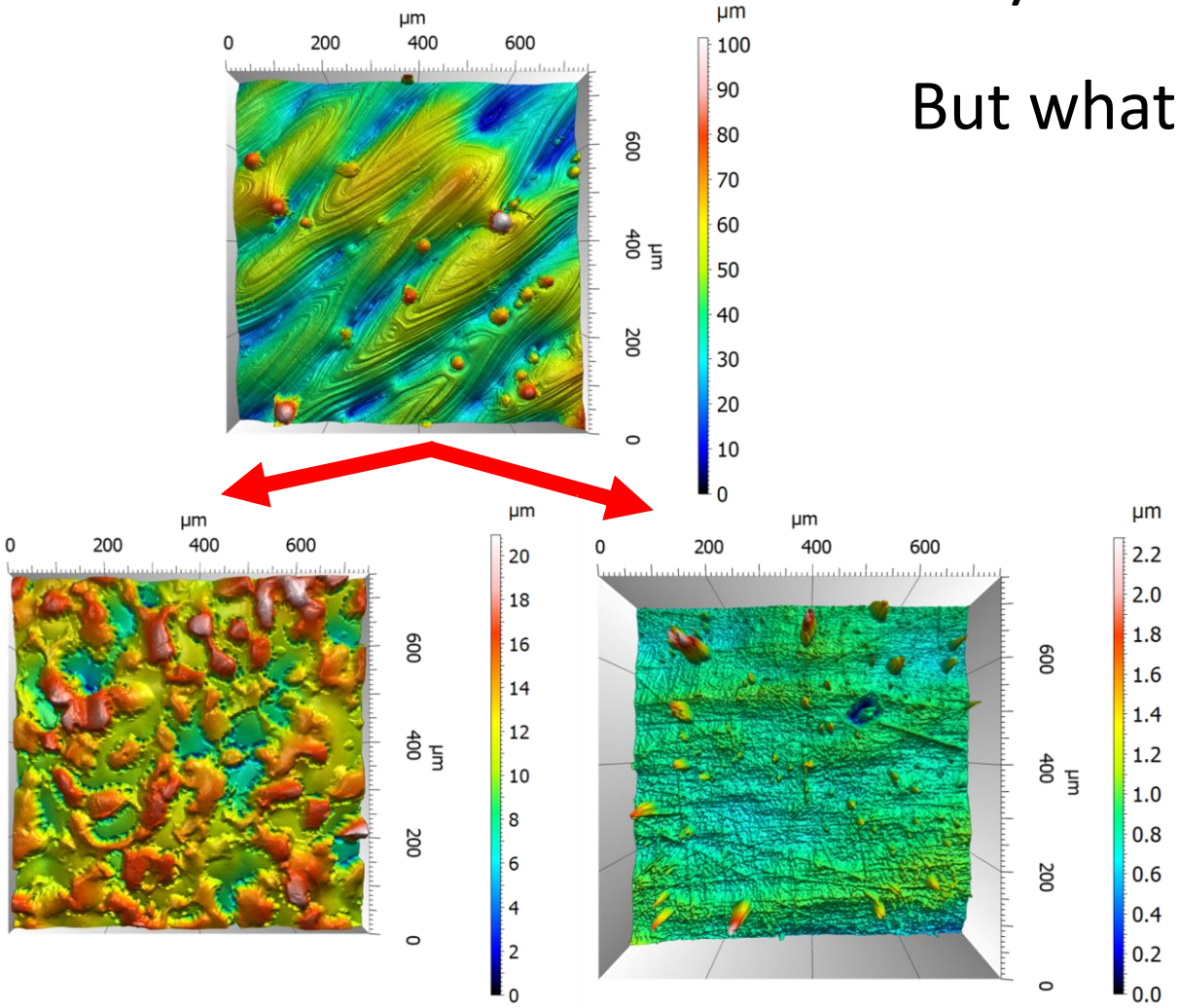




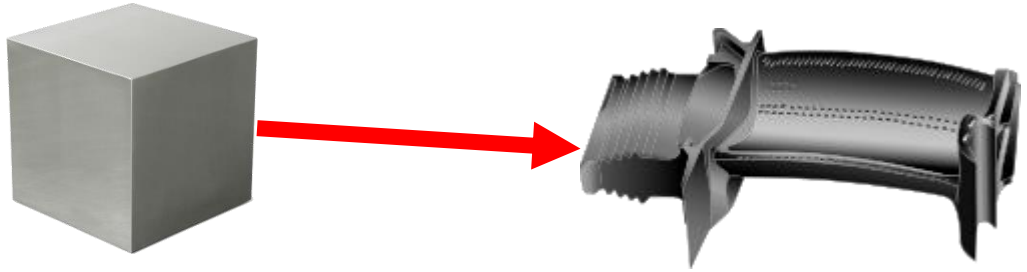
Thompson et al 2017 *Ann. CIRP* **66**, Senin et al 2017 *Meas. Sci. Technol.* **28**, Towsend et al 2017 *Prec. Eng.* **48**
Fox et al 2017 *euspen/ASPE SIG Dimensional accuracy and surface finish in additive manufacturing*

…but challenges remain!

XCT has shown to be capable of measuring the relatively rough additively manufactured surfaces of today



But what about in an industrial environment?



Or about the surfaces of tomorrow?

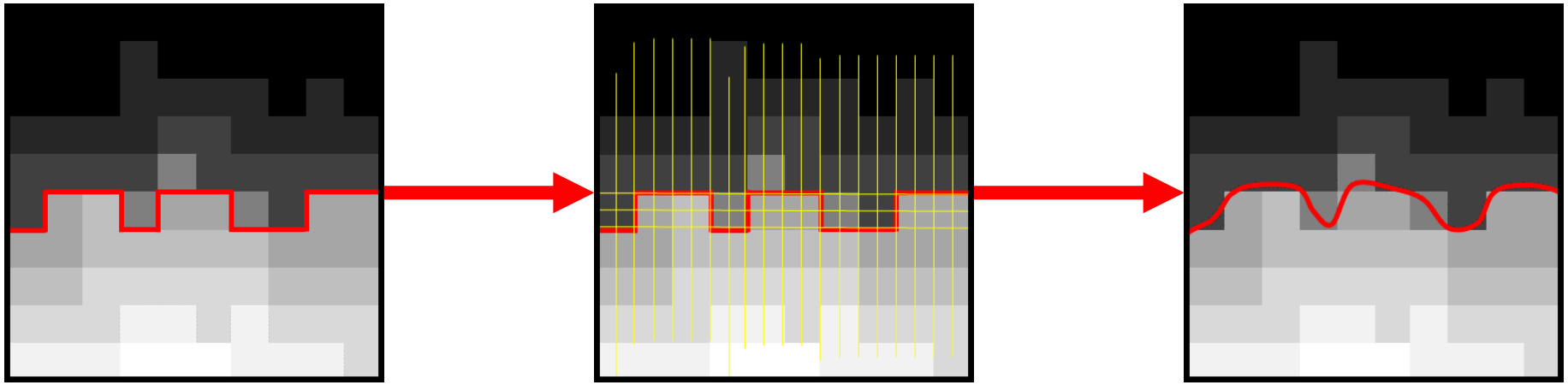
And what about when we need to measure much smoother surfaces?

Understanding our limits

We don't yet know how good we can get with XCT, because XCT resolution is ambiguous

Is it a voxel? Or is it smaller? (As software manufacturers would have us believe)

Local surface determination in VG Studio MAX



Until we can calibrate, we have to test empirically, because industry wants to measure these surfaces now

Keeping it relevant, let's test with industrial case studies

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Case studies and methods

Case study 1

Additively manufactured Ti6Al4V cube of size (20 × 20 × 20) mm containing internal channels, supplied by 3TRPD

Internal and external rough surfaces, typical of surfaces examined in the literature

Supplied by 3TRPD

XCT measurements of whole part, then milled to allow access to surface of interest

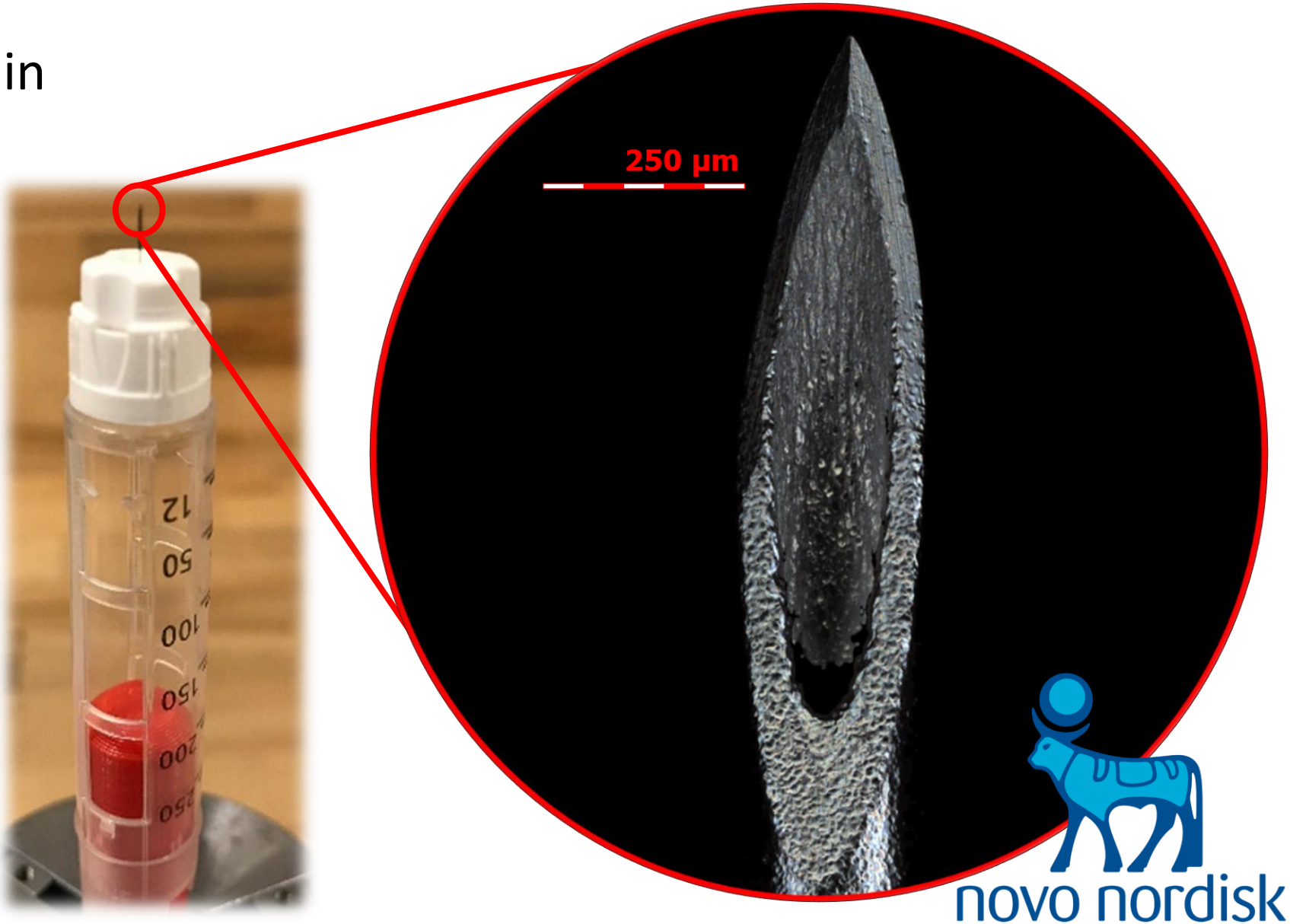
Case study 2

NovoNordisk ‘market’ insulin needle made from Silicone coated stainless steel

Externally smooth, internally rough

Surfaces of interest on the interior of the part

Accessible end of needle measured



novo nordisk

Case Study 3

Child's toy mask made of acrylonitrile butadiene styrene (ABS)

Smoother than parts commonly measured using XCT

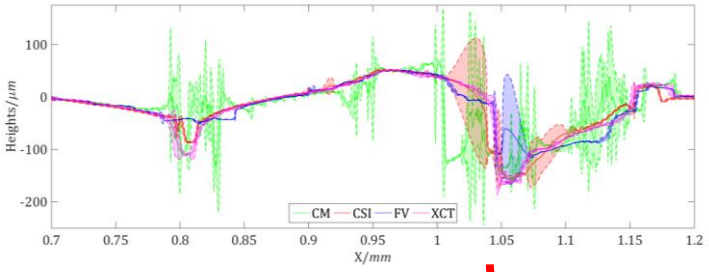
Complex form, with inaccessible surfaces

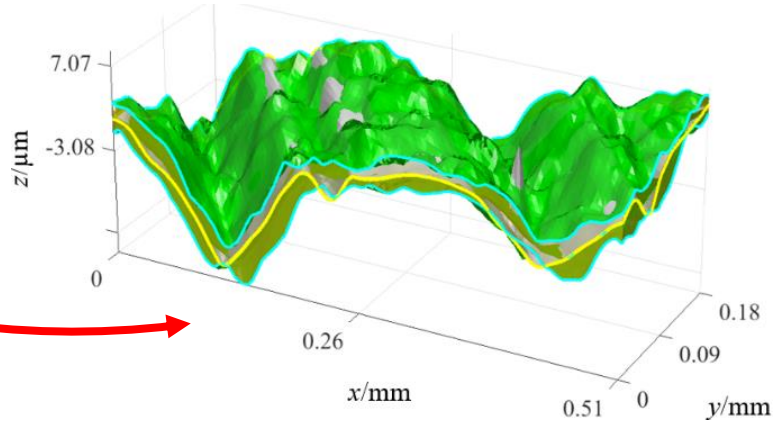
Accessible surface of 'nose' measured

Comparison methods

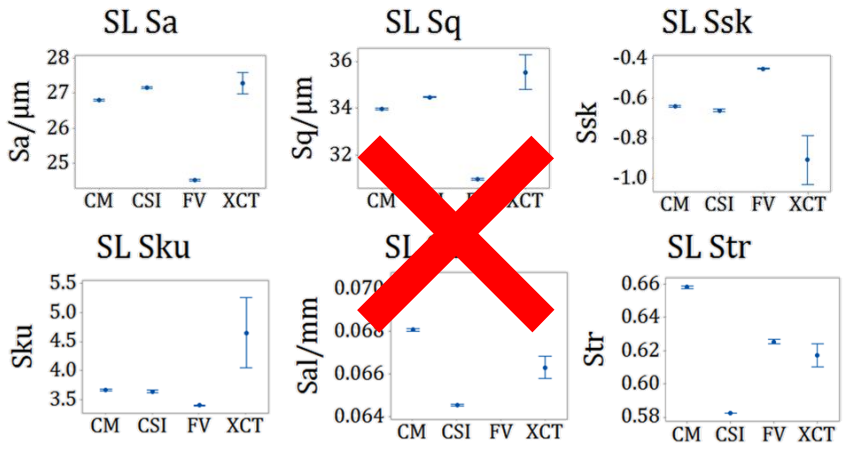
Lots of work now shows that a simple parameter study will provide statistical discrepancies between measuring instruments, even when instruments' spatial measurement bandwidths are matched

Instead, we will perform a direct statistical comparison of topographies





Modelling is based on building confidence intervals of *z* values at 95 % confidence at each *x*,*y* location of the topography. CI estimation is performed considering each *x*,*y* location as an independent variable and using t-distributions to estimate CIs.



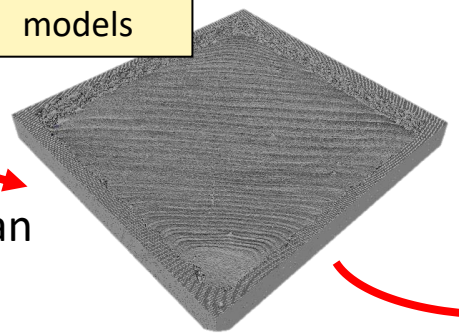
We can then estimate surface repeatability (i.e. precision) from mean confidence interval width, and the average bias between data acquired using different systems (i.e. accuracy)

XCT Surface measurement and comparison

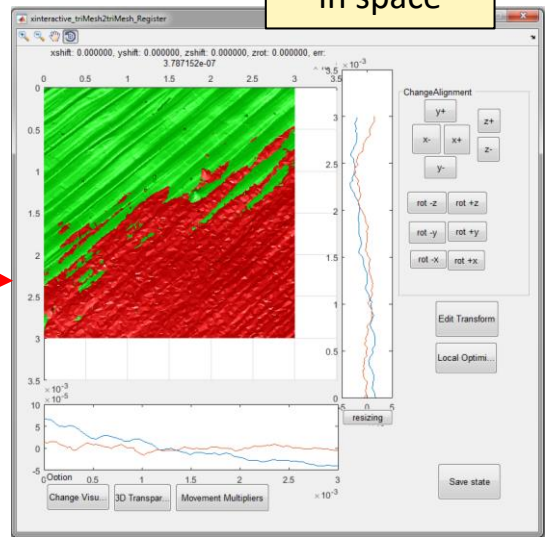
XCT scanner

XCT scan

Triangulated models

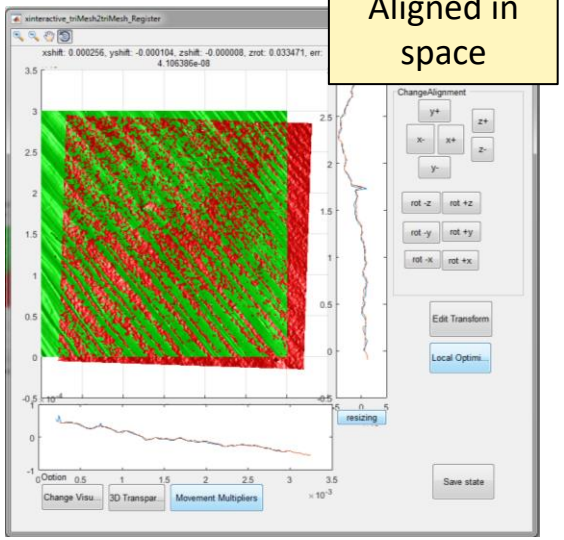


Unaligned in space



Alignment in 6 degrees of freedom

Aligned in space



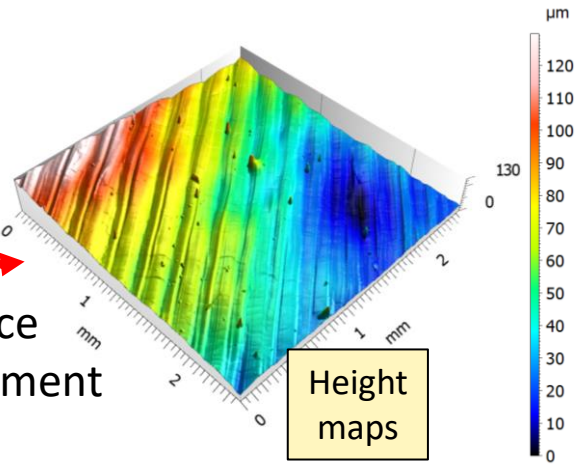
Raster scanning at defined pixel spacing, intrinsically matches bandwidths

Note: Images of instruments are *arbitrarily* chosen here as references – as with all our work, we are instrument agnostic

5 replicates taken for each measurement, of the same region of interest

Focus variation microscopy (FV) and Coherence scanning interferometry (CSI)

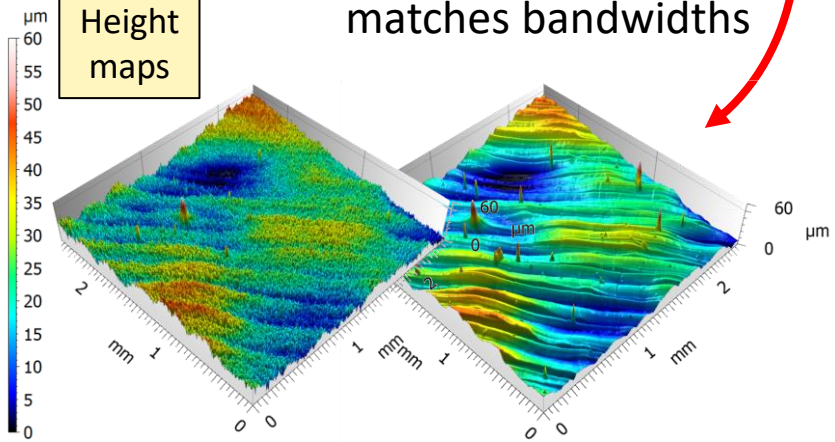
Surface measurement



Height maps

Triangulation

Height maps



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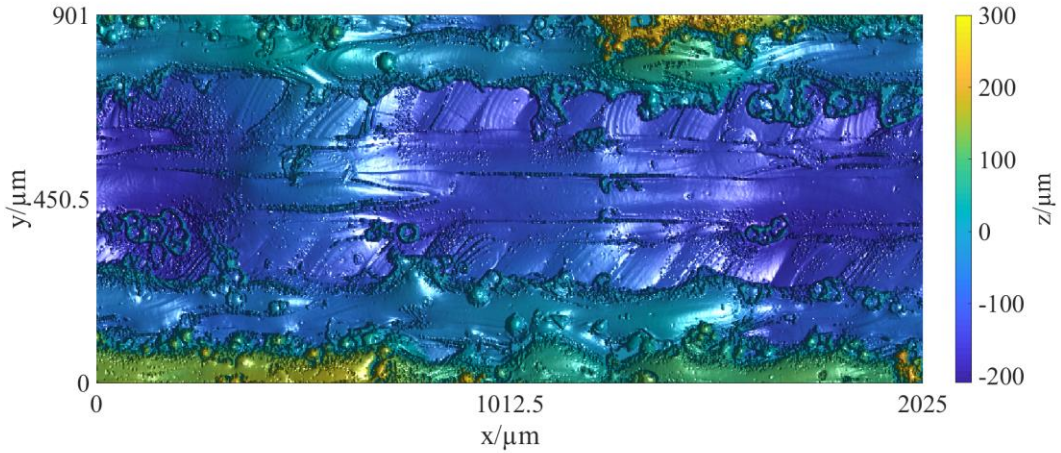
Results and discussion

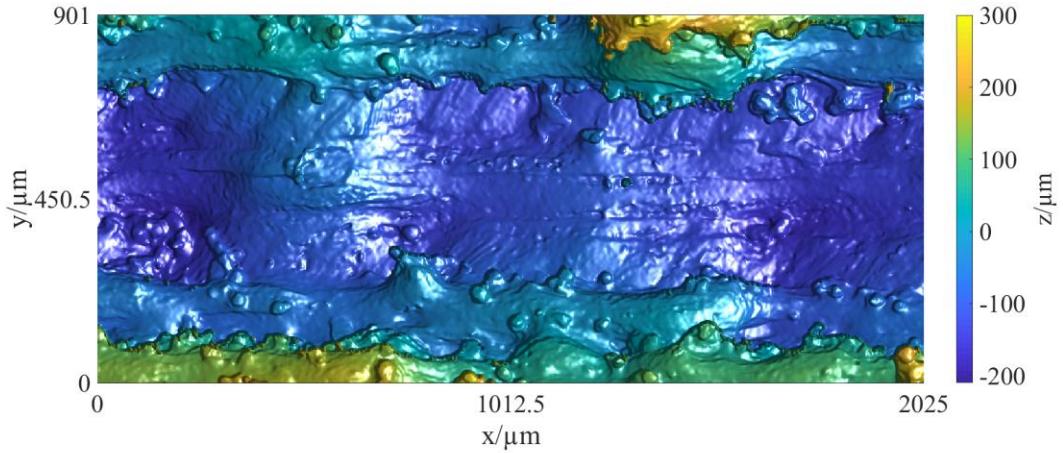
Case study 1 (Ti6Al4V Cube) visualisations

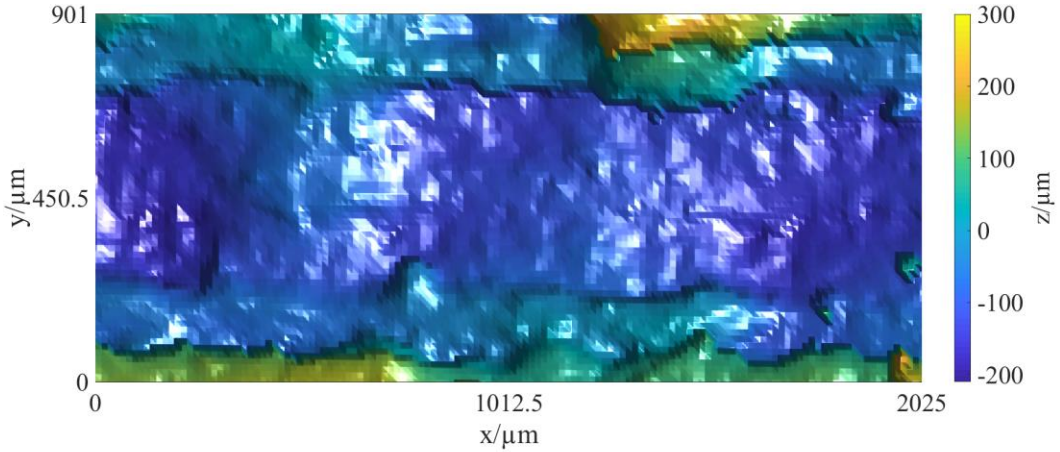
Example individual datasets from each measurement setup

CSI



FV





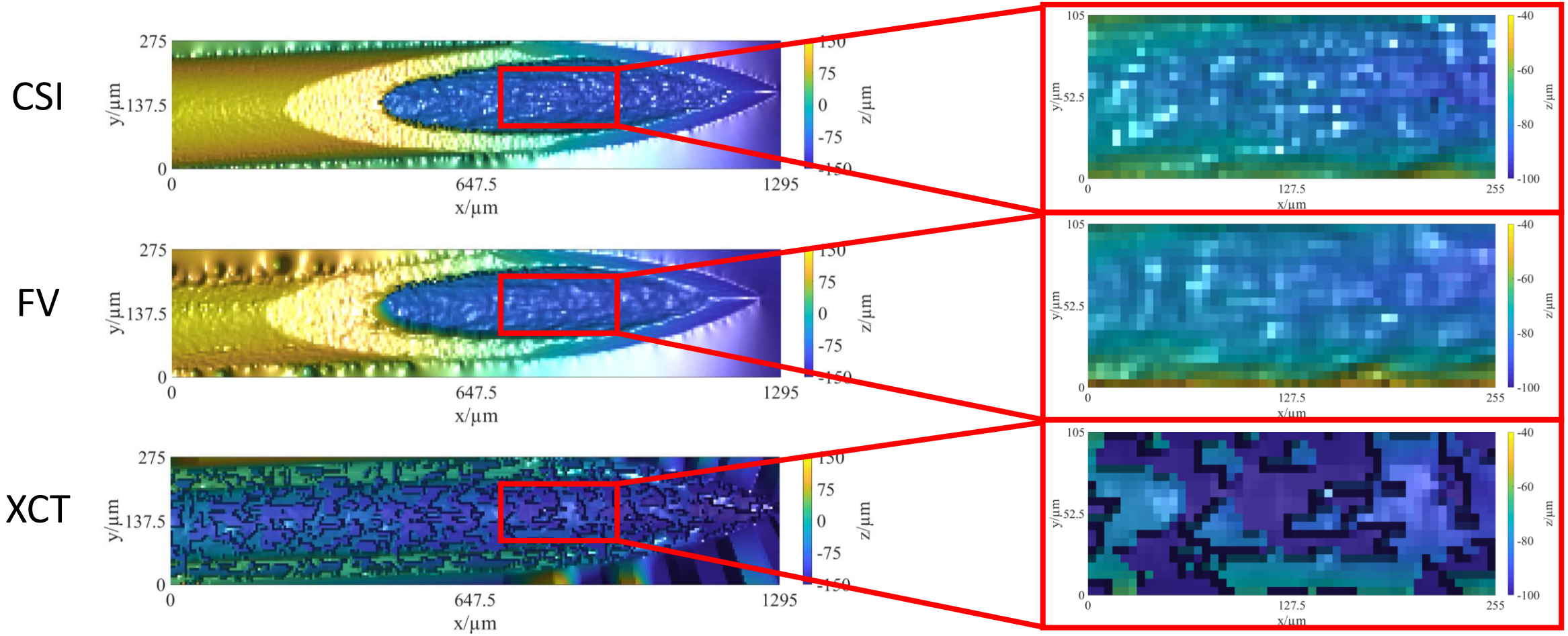
XCT

XCT Voxel size: 18.2 µm
Pixel spacing: 0.5 µm

CSI objective: 20× (NA 0.40, lat res 0.68 µm)
FV objective: (NA 0.40, lat res 3 µm)

Case study 2 (Market needle) visualisations

Example individual datasets from each measurement setup



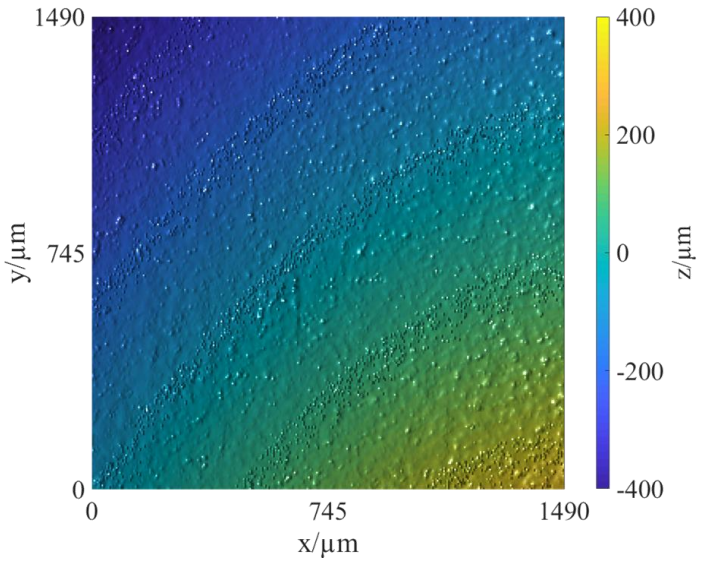
XCT Voxel size: 5 µm
Pixel spacing: 5 µm

CSI objective: 5.5× (NA 0.15, lat res 1.9 µm)
FV objective: (NA 0.40, lat res 3 µm)

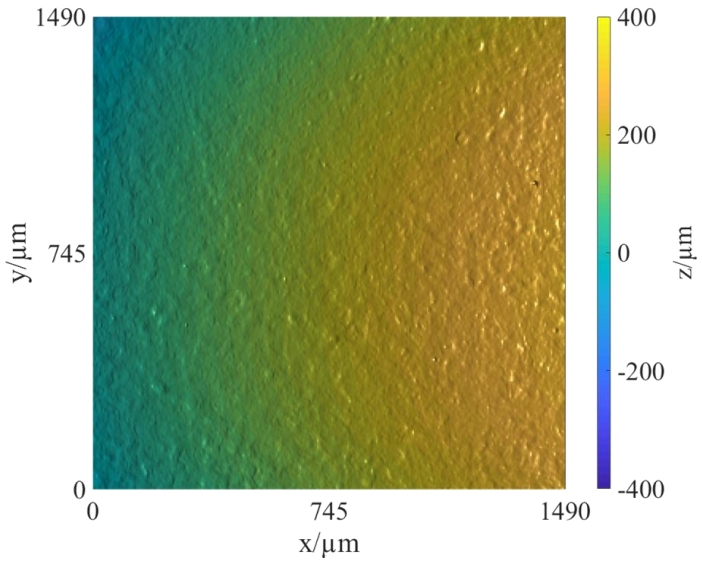
Case study 3 (Toy mask) visualisations

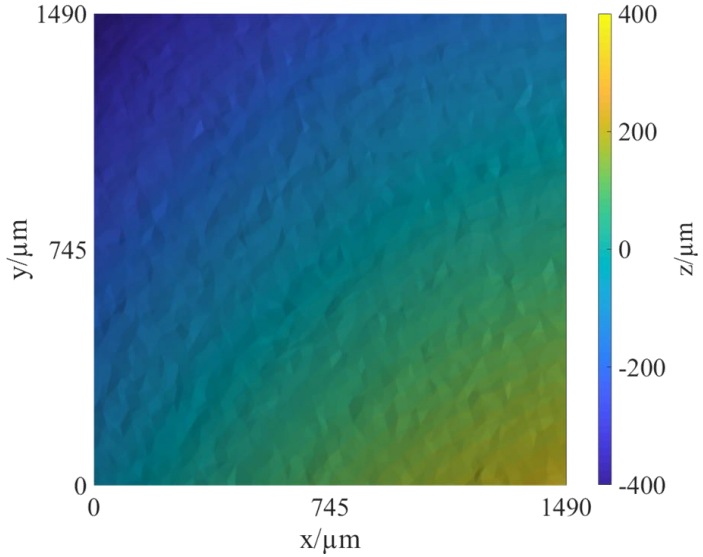
Example individual datasets from each measurement setup

CSI



FV





XCT

Note: poor alignment between CSI and FV due to a lack of fiducials), so data must be reacquired of the correct area.

However, alignment between FV replicate measurements is good

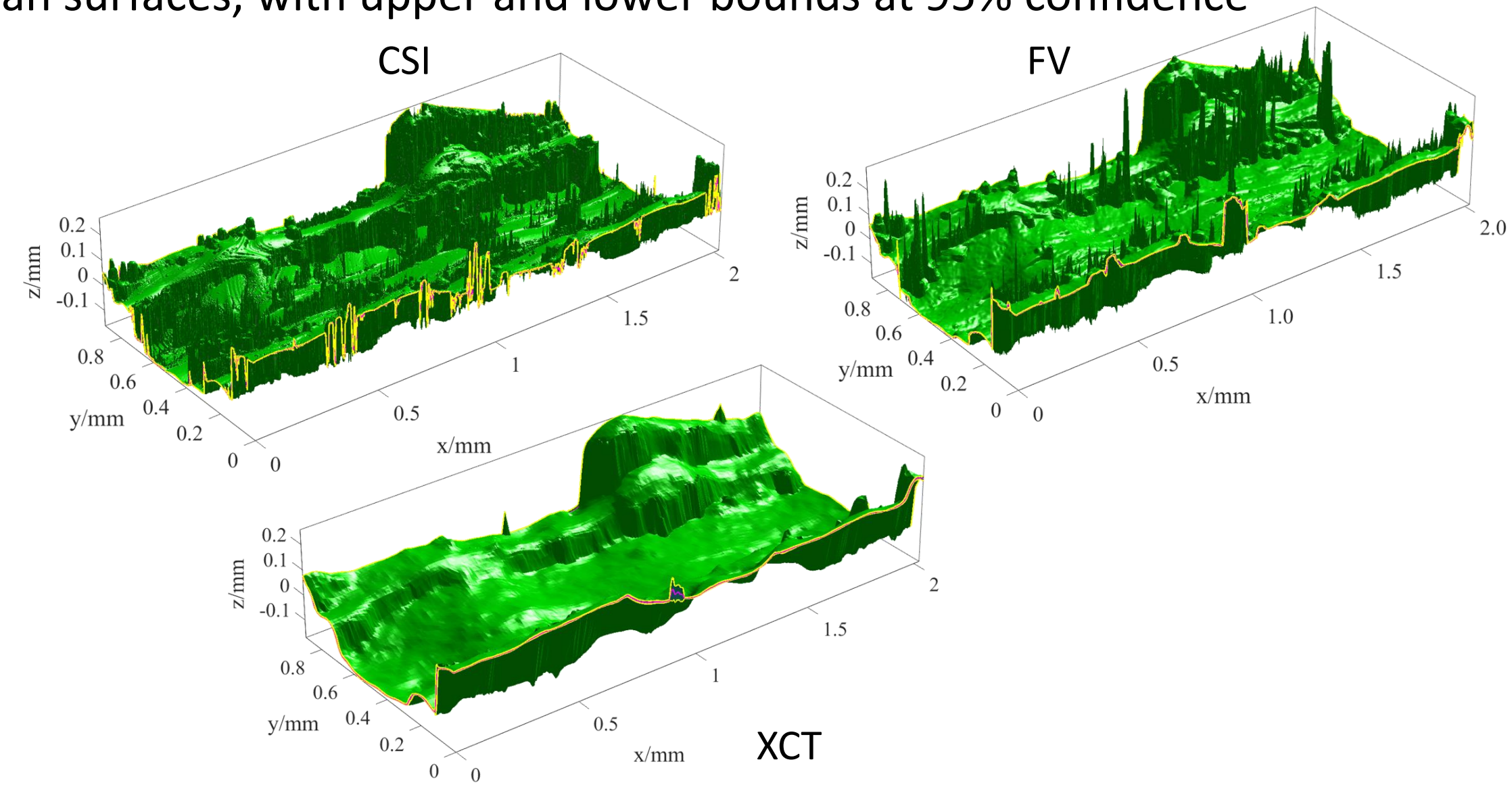
Therefore, CI width information remains valid in this study but the bias should be discounted

XCT Voxel size: 20 µm
Pixel spacing: 5 µm

CSI objective: 5.5× (NA 0.15, lat res 1.9 µm)
FV objective: (NA 0.40, lat res 3 µm)

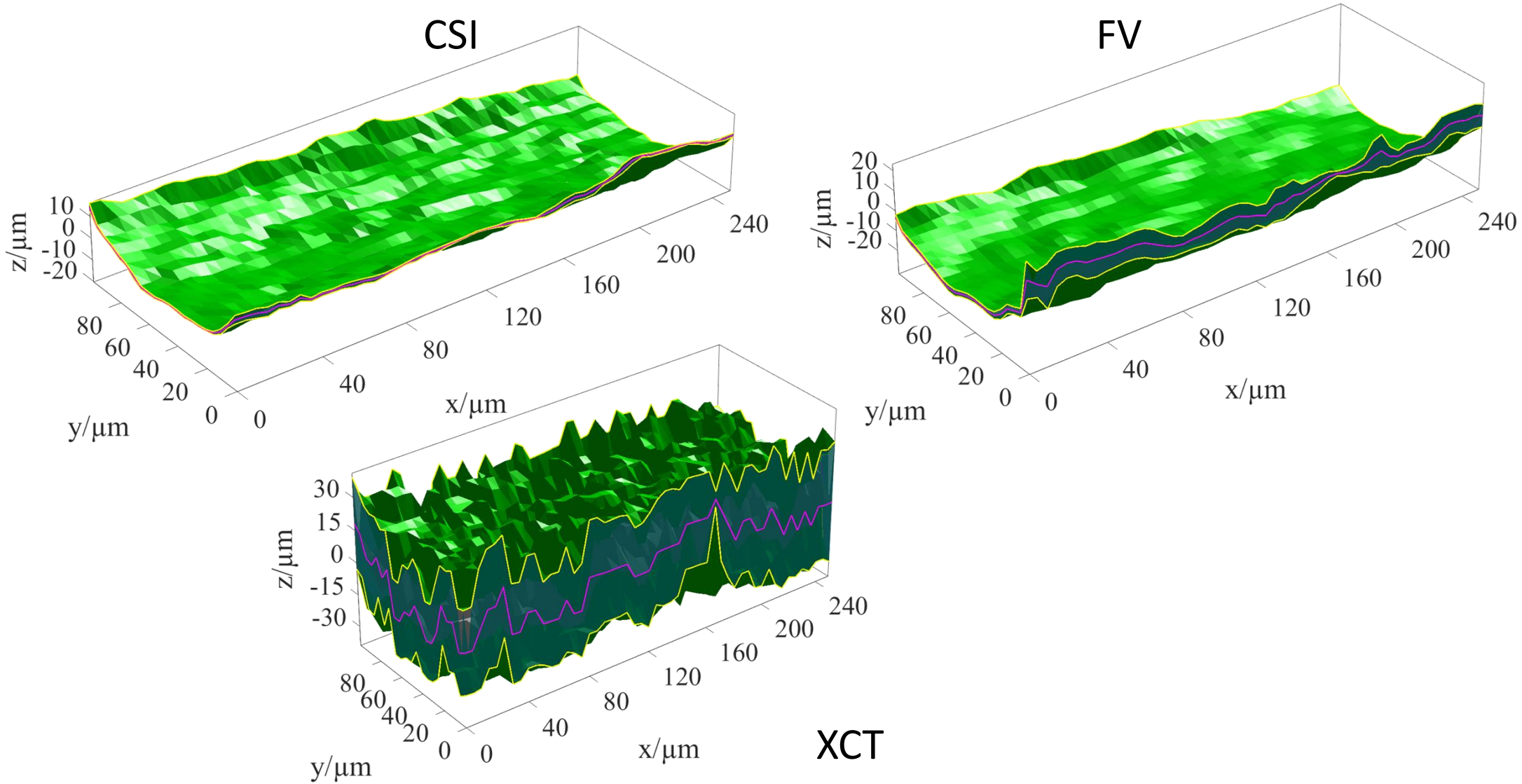
Case study 1 (Ti6Al4V Cube) statistical models

Mean surfaces, with upper and lower bounds at 95% confidence



Case study 2 (Market needle) statistical models

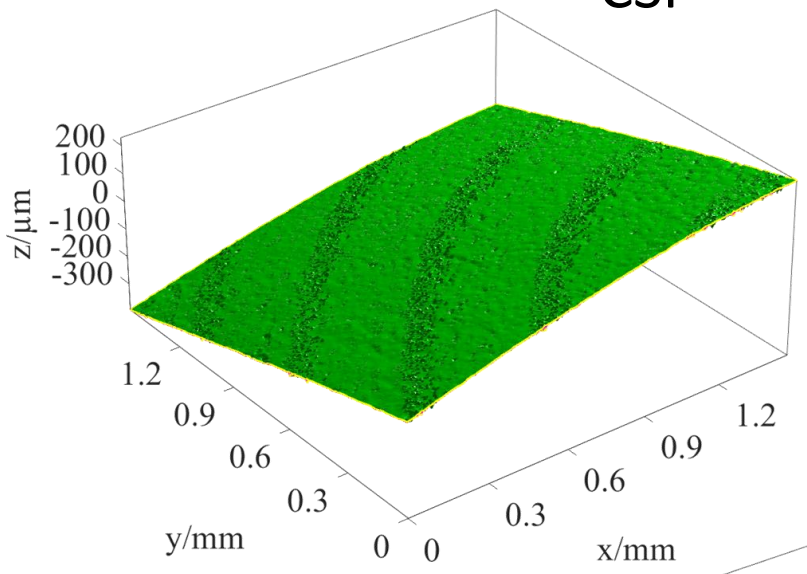
Mean surfaces, with upper and lower bounds at 95% confidence



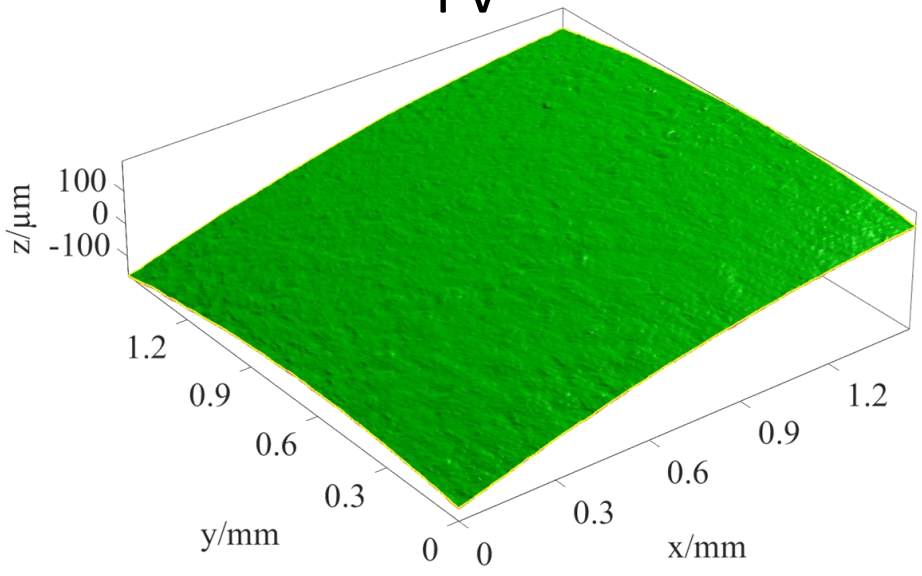
Case study 3 (Toy mask) statistical models

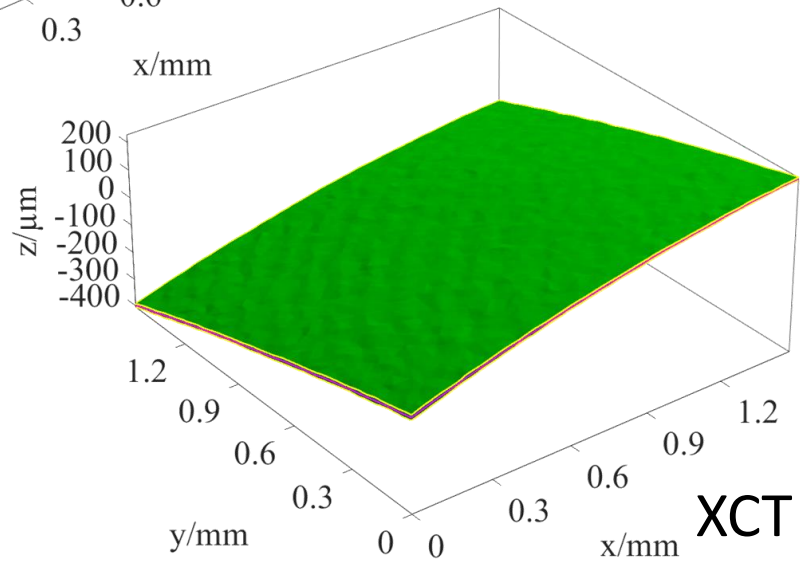
Mean surfaces, with upper and lower bounds at 95% confidence

CSI



FV



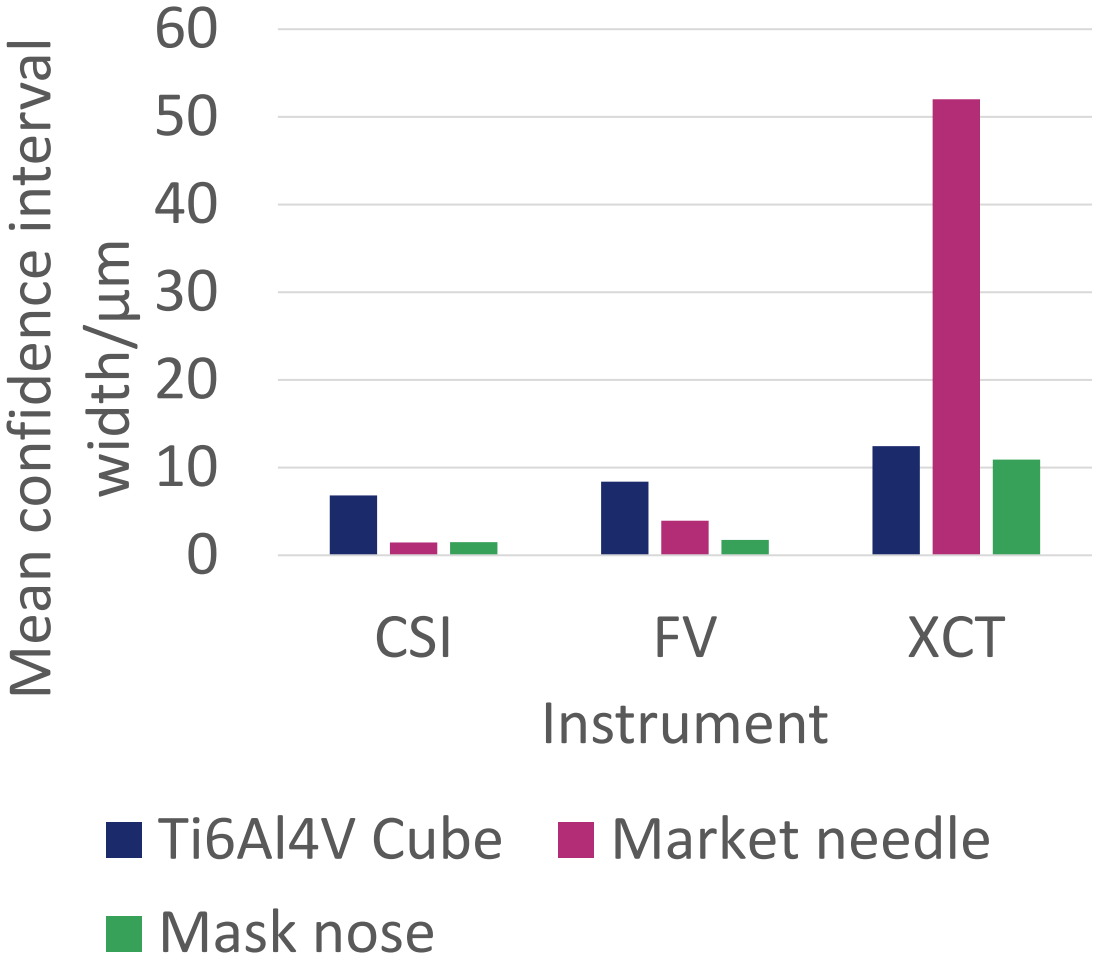


XCT

Case study repeatability and bias

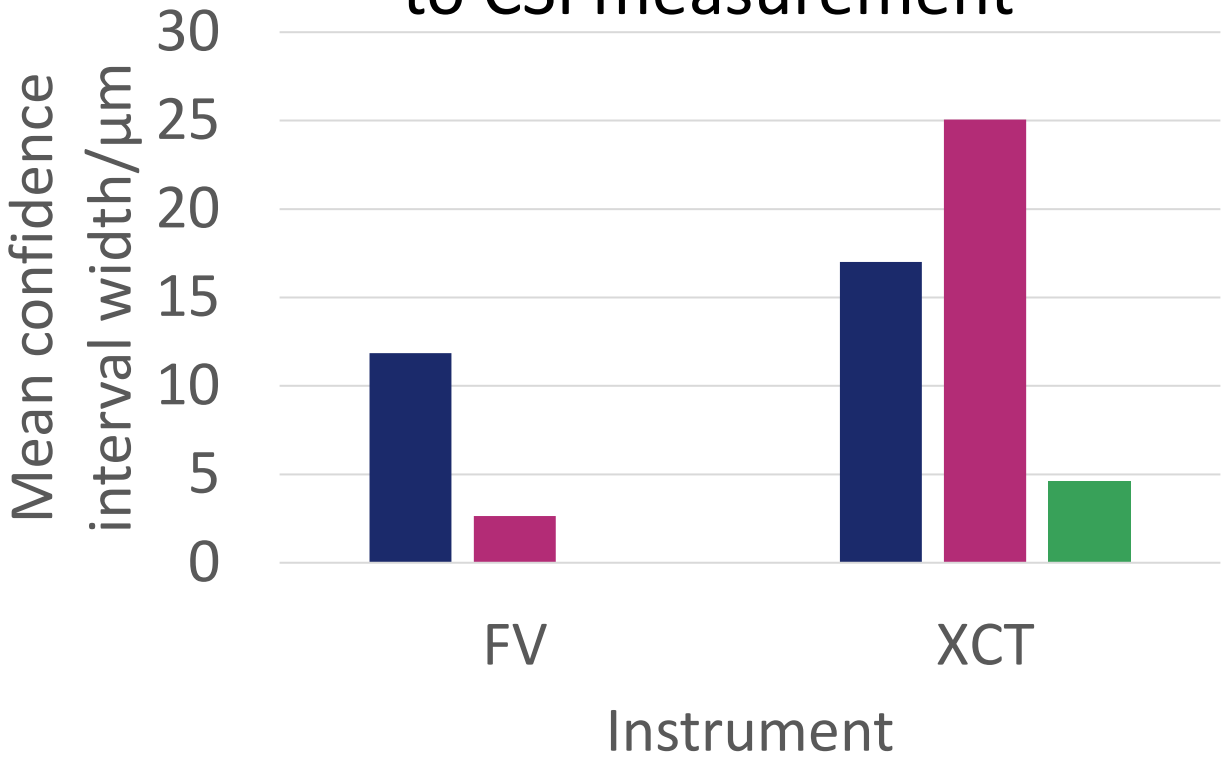
(Precision)

Repeatability from mean confidence interval width



(Accuracy)

Arithmetic average of bias in height determination with respect to CSI measurement



Note: CSI is *arbitrarily* chosen here as a reference, it does not necessarily represent the best measurement choice

Note: Bias between CSI and FV in Mask nose case discounted

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Conclusions and outlook

Conclusions

XCT surface measurement has been now applied to industrial test cases

Case studies were of mixed success:

- In some cases, XCT was similarly repeatable to the optical methods, while arithmetic average bias between the XCT/optical datasets was comparable to the arithmetic average bias between the optical/optical datasets
- In other cases, XCT repeatability was poorer, and arithmetic average bias between the XCT/optical datasets was notably larger than the arithmetic average bias between the optical/optical datasets

XCT was clearly more capable of measuring the rougher surfaces than the smoother surfaces

Future work

These three case studies represent the first few of a program of case studies, demonstrating the use of XCT in industrial surface measurement

Steps can always be taken to optimise measurement instrument settings, and further measurement may result in improved results over those discussed in this talk

Calibration of XCT systems for surface measurement is the vital, logical next step

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Manufacturing Metrology Team at Nottingham

Thank you!

Thanks also to 3TRPD and NovoNordisk for samples, and DTI for XCT data

3T

novo nordisk

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Horizon 2020

EPSRC Centre for Doctoral Training in Ultra Precision Engineering

EPSRC Engineering and Physical Sciences Research Council

EPSRC Centre for Doctoral Training in Additive Manufacturing

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