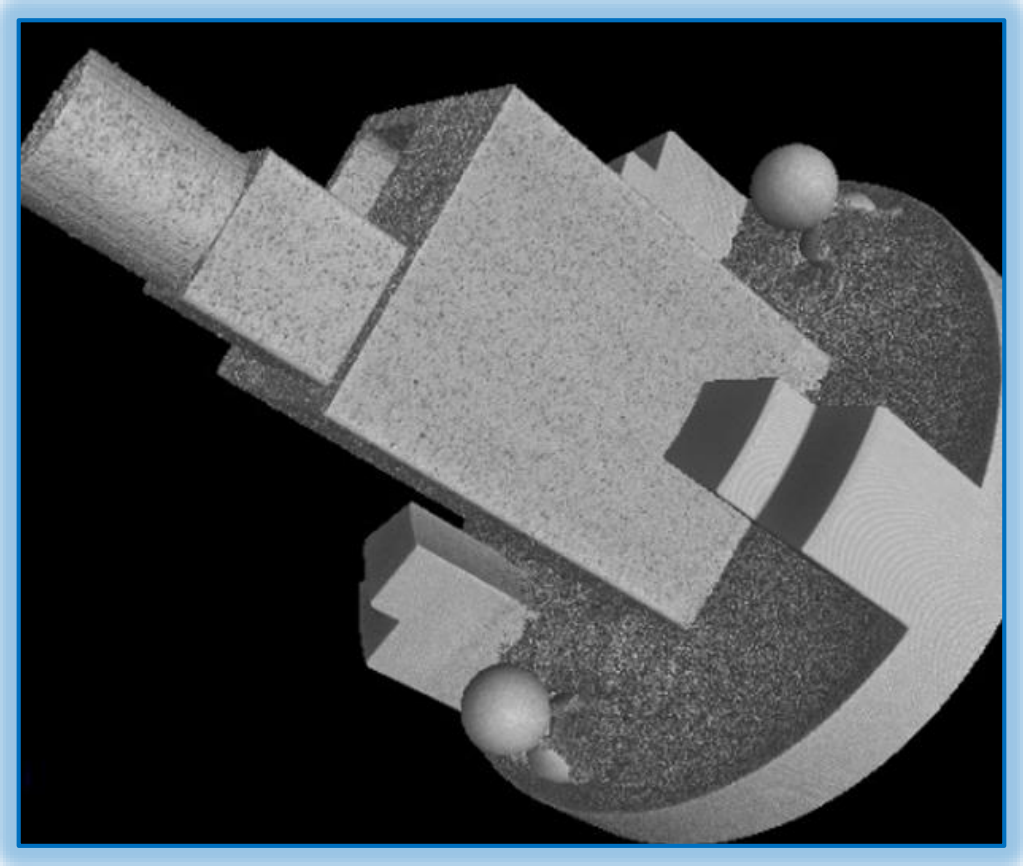
NPL
National Physical Laboratory

δXCT
0 1 2 3 4 5 6 7 8 9 10 NPL 2016

Dimensional X-ray Computed Tomography Conference 2016

Tuesday 10th May 2016
National Physical Laboratory, Teddington, United Kingdom



Delegate Package

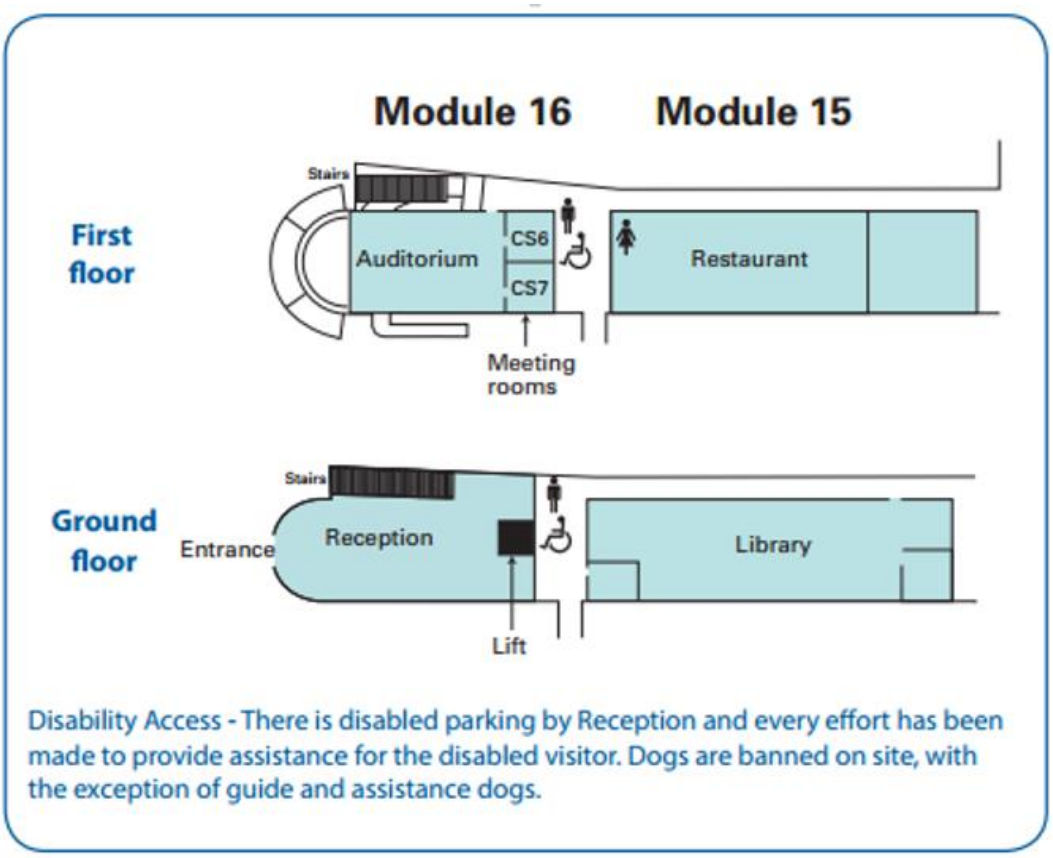
Welcome to NPL…

The National Physical Laboratory (NPL) is the UK's National Measurement Institute and is a world-leading centre of excellence in developing and applying the most accurate measurement standards, science and technology available.

For more than a century NPL has developed and maintained the nation's primary measurement standards.

These standards underpin the National Measurement System infrastructure of traceability throughout the UK and the world, realising accuracy and consistency of measurement. NPL ensures that cutting-edge measurement science and technology have a positive impact in the real world, delivers world-leading measurement solutions that are critical to commercial research and development, and supports business success across the UK and the globe.

Floor map of the venue



Dear delegates,

The organising committee takes great pleasure in welcoming you to the first Dimensional X-ray Computed Tomography Conference organised by the National Physical Laboratory.

This one day conference will address the current state-of-the-art development of dimensional X-ray computed tomography (XCT), the challenges associated with this technology and what is required to develop XCT for dimensional metrology to fulfill the urgent requirements from manufacturing industry, medicine and scientific research. This conference brings together experts in the field from around the world with the aim to share knowledge and to gain insight and inspiration from others.

The conference has a diverse programme. Oral presentations will be delivered by invited speakers and selected poster presentations will be given by scientists and students to demonstrate the latest developments. A discussion session will be included to develop ideas regarding how to transfer knowledge and ideas between science laboratories, research institutes and industries. Networking opportunities will also be provided throughout the event.

We truly hope that this conference serves as both a UK and an international platform for fruitful communication between the scientific and industrial communities. We also hope that either today or at another time, you take the opportunity to visit the diverse range of specialised laboratories at NPL and get a chance to interact with our scientists directly.

We would like to thank the exhibitors for their participation and to acknowledge the financial support of the UK National Measurement Office (NMO).

We hope you enjoy your day!

Kind Regards,

Organising committee

Wireless network for visitors

A wireless network is available in module 16 (reception and auditorium/ meeting rooms) and module 15 (Newton's restaurant and library).
The visitor's guest network is called GuestAccess.

To connect to the guest network:

1. Connect to the GuestAccess network.
2. Open your internet browser.
3. Accept the unsigned certificate if prompted to do so.
4. Log in with USERNAME: guest PASSWORD: teddington

Programme

Tuesday 10th May 2016

09:30 Registration

Session 1

09:45 Opening talk, Michael McCarthy, National Physical Laboratory

10:05 Paul Bills, University of Huddersfield

10:25 Andrew Lodge, Rolls-Royce

10:45 Refreshment break

Session 2

11:15 Robert Speller, University College London

11:35 Moataz Attallah, University of Birmingham

11:55 Ian Sinclair, University of Southampton

12:15 David Bate, Nikon Metrology

12:35 Lunch Break and poster presentations (issue lab tour tickets)

Session 3

13:35 David Eatock, Airbus Group Innovations

13:55 Wenjuan Sun and Stephen Brown, National Physical Laboratory

14:15 Joseph Lifton, University of Southampton

14:35 Robert Atwood, Diamond Light Source

14:55 Refreshment break

Session 4

15:15 Jay Warnett, University of Warwick

15:35 Nick Brierley, Manufacturing Technology Centre

15:55 Discussion of future works and collaborations

16:25 Event close

16:30 Lab tour (optional)

Oral Presentations - Abstracts

(Invited speakers' names are in bold)

Session 1

Developments towards verifying the performance of dimensional XCT systems

Michael McCarthy
National Physical Laboratory, Hampton Road, Teddington, TW11 0LW, UK

Dimensional measurements made using X-ray computed tomography (XCT) based coordinate measuring systems are not currently traceable to the unit of length, the metre. This presentation reviews the traceability of the metre and provides examples as to how this unit is disseminated to industry. Performance verification methods, already established to support measurement engineers using a range coordinate measuring systems are described. Finally, current progress on the development of an internationally agreed dimensional verification standard for XCT systems is discussed.

Characterization of complex additive manufactured structures for the medical device industry using computed tomography

Paul Bills, Paras Shah, Andrew Townsend, Liam Blunt, Radu Racasan
EPSRC Centre for Innovative Manufacturing in Advanced Metrology, University of Huddersfield, Huddersfield, HD1 3DH, UK

Abstract
Highly complex dendritic lattice structures can be produced with the aid of additive manufacturing (AM) allowing for more geometric freedom than traditional manufacturing techniques, and considerably less resources and cost. Currently AM methods lack true reproducibility, meaning that in some cases large numbers of components have to be scrapped or reworked. Therefore there is a clamour within industry to develop a robust and reliable methodology for characterising non-standard geometric dimensioning and tolerancing (GD&T) features using non-destructive evaluation. With potential 'prints' having a high probability of requiring further input using traditional manufacturing processes on mechanically interactive surfaces accurate specification of these complex structures is vital from a quality as well as regulatory perspective.

There is a growing clamour in the direction of investigating the efficacy and practicality of using computed tomography (CT) to both qualitatively and quantitatively analyse AM produced components, however, with both technologies and standards at a relatively early development and acceptance stage in industry a number of challenges exist in trying to achieve integrated valid subsurface AM feature measurements using CT.

This presentation will highlight the development of techniques used to characterise representative AM medical device-relevant structures and will further discuss best practices, tests and controls to assess integrity of build.

CT Measurement of turbine blades, present and future

Andrew Lodge
Rolls-Royce, Rolls-Royce plc, PO Box 31, Derbyshire, DE24 8BJ, UK

Abstract
Rolls-Royce currently uses X Ray CT to measure internal structures of single crystal High Pressure and Intermediate Pressure turbine blades at the Advanced Blade Casting Facility in Rotherham. As future turbine designs increase in complexity and reduce in size, there is a reliance on developing measurement techniques that are capable, reliable, and give confidence to engineers that design intent has been met. This presentation looks at existing CT measurement processes at Rolls-Royce, how CT measurement will be central to future turbine blade design, and what progress is required to keep pace with turbine innovation.

Session 2

Quantitative analysis of tissue using microCT

Robert Speller
University College London, Gower St, London WC1E 6BT, UK

Abstract
Most diagnostic X-ray examinations (planar or CT) are undertaken in order to look at the shapes and sizes of different structures in the body. However, there are many examples where characterising the different tissues would significantly enhance the diagnosis. A good example of this is the role of the Ca/P ratio in bone tissue. It has been shown that low Ca/P in bone is an indicator of poor bone quality. However, the spatial distribution of this ratio and its role in governing the strength of a given bone is still an area of active research that could lead to improved patient management. This talk will look at the use of microCT to characterise bone tissue based upon the estimation of effective atomic numbers. Other probes can be used in a microCT configuration and one that has shown promise in analysing breast cancer is the use of X-ray diffraction CT. If time allows this topic will also be considered.

XCT as a method for analysing the Influence of SLM laser processing parameters on porosity

Moataz Attallah[1], Jan White[1], Wenjuan Sun[2], Peter Woolliams[2]
[1] University of Birmingham, School of Metallurgy and Materials, Edgbaston, B15 2TT, UK
[2] National Physical Laboratory (NPL), Teddington, Middlesex, TW11 0LW, UK

Abstract
Selective laser melting (SLM) involves the consecutive melting of thin powder layers with a laser in order to consolidate a much larger component. By careful control of the laser processing parameters such as laser power, scanning speed, hatch spacing and layer thickness, the melt pool behaviour can be altered with a view to maximising the structural integrity. XCT will be discussed as a method for analysing defects, porosity and voids produced as the laser processing parameters are altered. The results are compared to optical microscopy methods showing the merits of both techniques to provide an effective overall method for characterisation and process validation. By showing the difficulties in inspection of small SLM components, the difficulties faced when qualifying large industrially produced components are highlighted.

Application of computed tomography in damage measurement and simulation in structural composites

Ian Sinclair
University of Southampton, University Road, Southampton, SO17 1BJ, UK

Abstract
The incidence of complex, multi-scale failure processes is well recognised in fibre reinforced laminates. The precise chronology, geometry and potential interaction between mechanisms has historically been poorly quantified, in terms of both experimental assessment and simulation. Contemporary X-ray computed tomography (CT) methods may provide vital model initialisation and validation input to composites simulation efforts, with this presentation discussing:
(a) a variety of laboratory and synchrotron imaging configurations as applied to carbon fibre epoxy composites, including in situ and ex situ tests, and the use of laminography in laterally extended samples
(b) specific comparisons and calibration of simulations that address fibre breaks, intra-laminar and inter-laminar fracture, including both crack initiation and growth processes.

Error sources in CT systems and practical methods of correction

David Bate
Nikon Metrology, Unit 5, Icknield Industrial Estate, Herts HP23 4JX, UK

Abstract

This paper addresses the error sources in a CT system. These errors occur in several areas:

- X-ray generation
- Sample interaction
- Sample manipulation
- Detection
- Reconstruction

The first error source to be considered will be Beam hardening. The method of X-ray generation in microfocus X-ray leads to polychromatic beams with subsequent non-linear absorption.

There are two practical methods that can be used for correction (1) filtration, by placing thin foils in the beam the X-ray spectrum can be adjusted. (2) 'Beam hardening' correction can be used, in this method a measured LUT or similar is created to correct the images to appear as if the absorption is linear. Without this, the interior of the object will appear less dense than the surface which leads to problems finding a surface, particularly for interior edges.

The second error source considered will be the geometry errors caused by incorrect positioning of the sample. It will be shown how they can be critical to correct metrology. These can be corrected either by pre-CT set up (laser interferometry etc) or through traceable CT scans (comparator method).

The final section will look at the issues of surface determination in CT and the impact that this can have on the accuracy of CT metrology as well as the impact of other errors on this. The accuracy of the surface will depend on the reconstruction algorithm as well as the surface finding algorithm used. There are angular effects for material off the central plane when using Feldkamp based algorithms as well as errors due to lack of penetration.

While the paper will not cover every possible error in a CT metrology system examples will be shown to illustrate the possibilities of practical correction.

Session 3

XCT applications in aerospace additive manufacturing

David Eatock
Airbus Group Innovations, New Rd, Filton, Bristol BS34 7AT, UK

Abstract
The talk will cover the use of XCT in various elements of the additive manufacturing process chain both in terms of NDT and also dimensional inspection. In Airbus Group Innovations XCT has been investigated primarily as a non-destructive testing tool to understand the limitations of the process when examining defects in the down to 50 microns in finished AM parts. The technology is also used to provide quantitative data for powder samples in terms of density of powder particles, shape and size. With the drive towards more complex topology optimized structures with internal features, XCT for dimensional inspection is coming into play. Traditionally the cost of XCT for the NDT of AM parts has been prohibitive as a steady state production tool for either in house investment or external services but if the equipment and the process can be used to answer a multitude of quality assurance questions traditionally answered via other means then the technology may seem more affordable and practical. The challenge is to enable the systems to resolve data from defects in powder to the scale of the largest additively manufactured parts.

Developments in dimensional metrology in XCT at NPL

Wenjuan Sun, Stephen Brown
National Physical Laboratory, Hampton Road, Teddington, TW11 0LW, UK

Abstract
Recent advances in manufacturing technologies enable parts with complex external and internal features to be produced. However, the development of non-destructive testing (NDT) techniques to deliver the robust dimensional measurements of such parts is still in its infancy. X-ray computed tomography (XCT), due to its ability to visualise both the exterior and interior of complex parts, has found a niche in the market of NDT. The sources of error and their impact on dimensional measurements are not well understood.

NPL has conducted a series of projects to investigate the error sources inherent in XCT. This presentation provides an overview of NPL's current XCT related projects. These projects include the investigation of the quality of the X-ray source, the characteristic of the detector and the geometrical errors associated with the source, and the detector together with the rotation stage. Other errors considered include beam hardening and scattering. One of the projects relates to the measurements of additive manufacturing parts, where samples often exhibit complex external and internal features. An NPL reference sample has been developed and employed to investigate XCT measurement errors. The XCT results have been compared with data captured using a 3D optical scanning system and a conventional tactile based Cartesian coordinate measuring machine (CMM).

On the influence of scatter in X-ray CT for dimensional metrology

Joseph Lifton
University of Southampton, Malaysia Campus, No. 3, Jalan Canselor 1 Kota Ilmu Educity, Nusajaya, Johor, 79200, Malaysia.

Abstract
Scattered radiation contributes an unwanted background signal to radiographs in cone-beam X-ray computed tomography, this unwanted signal reduces the contrast of the reconstructed data and introduces artefacts such as streaking. The image degradation caused by scatter is thought to influence edge detection and therefore dimensional measurements. To investigate the influence of scatter on dimensional measurements the beam stop array scatter correction method is employed to compare measurement results before and after scatter correction. Results are presented for both mono and multi-material workpieces.

Towards accurate measurements with synchrotron tomography -- problems and pitfalls

Robert Atwood
Diamond Light Source, Diamond House, Harwell Science and Innovation Campus, Fermi Ave, Didcot OX11 0QX, UK

Abstract
Synchrotron X-ray tomography has given tremendous insight into the interior structure of many objects. The high flux and narrow bandwidth of the X-ray allows discrimination between very similar materials, and superior optics and detectors are now being used to resolve changes in the 3-d structure on the time scale of tens of milliseconds and observing the change in size and shape of structures during some process such as metallurgical forming or corrosion. But the synchrotron tomography system is not perfect. The parallel beam used much of the time requires scintillator detection and optical magnification and this introduces blurring, defects, and distortion. The push for finer time resolution involves tradeoff, under-exposing the images, pushing the limits of the detector, undersampling the tomography series by taking fewer angles, or allowing motion during each exposure. At high magnifications, the difficulty in manufacturing and maintaining the scintillator means that significant defects must be tolerated. Mathematical methods for improving the appearance of the tomography reconstructions are used and are constantly being improved, but have some effect on the dimensions of objects and resolution available. Examples from Diamond beamline I12 will illustrate the problems and the effects of some improvement schemes.

Session 4

Towards in-process x-ray CT for dimensional metrology

Jay Warnett
University of Warwick, International Manufacturing Centre, WMG, University of Warwick, Coventry CV4 7AL, UK

Abstract
X-ray Computed Tomography (CT) offers significant potential as a metrological tool, given the wealth of internal and external data that can be captured, much of which is inaccessible to conventional optical and tactile coordinate measurement machines (CMM). Typical lab-based CT can take upwards of 30 minutes to produce a 3D model of an object, making it unsuitable for volume production inspection applications. Recently a new generation of Real Time Tomography (RTT) x-ray CT has been developed for airport baggage inspections, utilising novel electronically switched x-ray sources instead of a rotating gantry. This enables bags to be scanned in a few seconds and 3D volume images produced in almost real time for qualitative assessment to identify potential threats. Such systems are able to scan objects as large as 600 mm in diameter at 500 mm/s providing almost real time data. The current voxel size of such a system is approximately 1mm - much larger than lab-based CT, but with significantly faster scan times is an attractive prospect to explore. We examine the potential of such systems for real time metrological inspection of additively manufactured parts. The measurement accuracy of the Rapiscan RRT110, an RTT airport baggage scanner, is evaluated by comparison to measurements from a metrologically confirmed CMM and those achieved by conventional lab-CT. It was found to produce an average absolute error of 0.18 mm that may already have some applications in the manufacturing line. While this is expectedly a greater error than lab-based CT, a number of adjustments are suggested that could improve resolution, making the technology viable for a broader range of in-line quality inspection applications, including cast and additively manufactured parts.

The state of the art in radiography: computed tomography for production

Nick Brierley
Manufacturing Technology Centre, Ansty Park, Coventry, CV7 9JU, UK

Abstract
Please contact the author for more information: Nick.Brierley@the-mtc.org

Poster session

Computed tomography: Influence of part position on measurement results

Amalija Horvatić[1], Biserka Runje[1], Igor Novak[2]
[1]Faculty of mechanical engineering and naval architecture, Ivana Lučića 5, 10 000 Zagreb, Croatia
[2]Oprema-strojevi d.d. Koprivnička 23, 42 230 Ludbreg, Croatia

Abstract
Computed tomography (CT) is a relatively new method in the field of dimensional measurement. It is a non destructive, non tactile coordinate method for dimensional measurements. Its advantage compared to other coordinate measurement methods is that it provides insight into internal geometry of measured parts without destroying them. However, due to large number of influential factors, measurement uncertainty is not yet defined and measurement traceability is still not achieved. One of the approaches to achieve traceability is to identify and determine all influential factors as well as their impact on measurements. In this paper, one of the uncertainty components - the position of the measured part - was observed. Standard uncertainty was calculated based on observations obtained under repeatability and reproducibility conditions. Measurements were conducted in three different object orientations and repeated four times. In accordance with the document JCGM 100 201x cd (revised Guide to the expression of uncertainty in measurement) from the year 2015 the Bayesian approach was used to evaluate the type A standard uncertainty component. The test sample was an aluminium cylinder specially shaped and manufactured so that, apart from the dimensional characteristic (length), two geometrical characteristics (flatness and parallelism) were investigated. Scanning was conducted on Nikon XTH 225, while the measurements of the scanned model were done in the software Volume Graphics StudioMAX 2.2. Finally, the results were compared with those obtained using the tactile coordinate measurement machine.

Investigation of the compatibility of X-CT measurement data to surface topography analysis

S. Lou, X. Jiang, W. Zeng, H. Abdul-Rahman, P. J. Scott
EPSRC Centre for Innovative Manufacturing in Advanced Metrology, University of Huddersfield, Queensgate, Huddersfield, HD1 3DH, UK

Abstract
In recent years X-CT metrology becomes more popular as a promising geometrical measurement technique. In comparison to traditional tactile and optical metrology techniques, X-CT has the unique advantage: it is a non-destructive method which can measure the complete internal and external geometry without constraint. Although X-CT has a limitation on the measurement of surface texture due to limited resolution, it is qualified for that of most of additive processed surfaces, which are featured by high roughness surface texture comprising a number of topographical features, such as bumps, step markings and surface pores.

The X-CT generated data structures for the object surface, either point cloud or triangular mesh, differ from the grid structure of traditional methods. To enable X-CT data structures compatible with surface topography, two strategies are investigated: One is to interpolate scattered points into grid structure. The other one is to perform surface analysis on triangular mesh. The pros and cons of two different routes are discussed and compared. The application of the surface analysis techniques e.g. filtration, segmentation, parameterisation etc. following two different strategies are illustrated respectively.

Assessment of residual coronal tooth structure post-endodontic cavity preparation using digital dental impressions and high-resolution micro-computed tomography

Nassr Al-Nuaimi
Department of Restorative Dentistry, King's College London Dental Institute, London, UK

Abstract

Objectives

The aim of this study was to evaluate the volumetric scanning accuracy and reliability of digital impressions for 3D measurement of residual coronal tooth structure post-endodontic cavity preparation, with reference to high-resolution micro-computed tomography (µCT).

Materials and Methods

Access cavities were cut in 34 human extracted molar teeth. All teeth were scanned with an intra-oral scanner (Test Scanner: 3M™ True Definition scanner - TrueDef) in high-resolution mode and µCT (Reference scanner: GE Locus SP µCT scanner, London, ON, Canada) in high (REF 1) and low (REF 2) resolution modes. Prior to scanning, quantification of the accuracy and precision of the TrueDef was performed using metrology gauge block and a profilometric tooth calibration model. Comparisons of volumetric accuracy and 3D deviations were performed using best-fit alignment (Geomagic® Control™). 3D deviations between test and reference scanners were expressed as mean (+/-) and maximum (+/-) values (µm).

Results

Data analysis showed no statistically significant difference in the volumetric measurements obtained from TrueDef, REF 1 and REF 2 µCT scans (p>0.05). Regarding the maximum deviations, TrueDef displayed greater 3D deviation (+27 µm / -33 µm) vs. REF 2 than vs. REF 1 (+16 µm / -32 µm). The mean and maximum positive deviation values between TrueDef and both µCT datasets were significantly different (p<0.001).

Conclusions

Within the limitations of this *ex vivo* study, it can be stated that the volumetric scanning accuracy using digital impressions of endodontically accessed teeth was comparable to the reference scanner. Further *in vivo* studies are required to confirm the current results under normal clinical parameters.

Clinical Relevance:

True Definition scanner produces accurate 3D models that can be very useful for the clinicians to estimate the residual coronal tooth structure following root canal access cavity preparation, which may have a prognostic predictor value for the outcome of endodontic treatment.

Observations on the performance of X-ray computed tomography when measuring a holeplate

Hannah Corcoran[1, 2], Stephen Brown[2], Stuart Robson[1], Michael McCarthy[2] and Robert Speller[1]

[1] *University College London, Gower Street, London, WC1E 6AR, UK*

[2] *National Physical Laboratory, Hampton Road, Teddington, TW11 0LW, UK*

Abstract

X-ray computed tomography (XCT) is a rising technology being used within many industries that require dimensional metrology. Many variables can affect the quality of dimensional metrology when imaging objects using XCT. Using a holeplate designed to exacerbate the apparent errors from XCT systems, this work will focus on the volume of material that the X-rays have to travel through and the orientation of the object. Multiple measurements including unidirectional and bidirectional lengths, radii of cylinders and the fit point deviations of fitted shapes are discussed. Results indicate the accuracy and precision of these dimensional measurements are affected by both the orientation of the holeplate and the amount of material the X-rays have travelled through.

Investigation of the focal spot drift in cone-beam industrial X-ray computed tomography

Nadia Flay[1, 3], Wenjuan Sun[1], Stephen Brown[1], Richard Leach[2], Thomas Blumensath[3]

[1] *National Physical Laboratory, Hampton Road, Teddington, Middlesex, TW11 0LW, UK*

[2] *University of Nottingham, University Park, Nottingham, NG7 2RD, UK*

[3] *University of Southampton, University Rd, Southampton, SO17 1BJ, UK*

Abstract

The purpose of this study was to conduct an investigation of the focal spot drift and its correlation with thermal behaviour of an XCT system. The novel experimental set-up and two reference objects (samples) were designed in such a way as to minimise the number of factors that can influence the positional stability of 2D projections. Both samples were small metal spheres surrounded by transparent materials. Sample 1 was a steel ball of 0.79 mm diameter embedded in the centre of a polyurethane cylinder of 10 mm diameter and 5.42 mm height. Sample 2 was a steel ball of 0.79 mm diameter attached to a borosilicate glass plate of 1 mm thickness. The nominal thermal expansion coefficient of polyurethane is $57.6 \times 10^{-6}\ K^{-1}$, of steel is $13 \times 10^{-6}\ K^{-1}$ and of borosilicate glass is $3.3 \times 10^{-6}\ K^{-1}$.

The experiments were performed with different starting temperature of the X-ray tube. The focal spot drift was calculated in both the *x* and the *y* axes. The long term stability of the system and the repeatability of the experiments were assessed for tube power below 6 W. The results from the experiments were compared to the results of the scan in which the stability of the sample was affected by the motion of the rotation stage.

Furthermore, the acquired data for the focal spot drift was used to simulate the projections of the steel sphere of 1 mm in diameter at magnification of 100. The projections were then reconstructed using Nikon CT Pro 3D software. The 3D volumes of the reconstructed spheres were analysed and compared.

Quantifying the deformation of chondrules in the Leoville meteorite using X-ray micro-CT

Natasha V. Almeida[1, 2], Caroline L. Smith[1], Dan Sykes[1], Hilary Downes[2], F. Ahmed[1], Sara. S. Russell[1]

[1] *Natural History Museum, Cromwell Road, London, SW7 5BD, UK*

[2] *Birkbeck College, University of London, Malet Place, London, WC1E 7HX, UK*

Abstract

Chondrules are silicate particles constituting a major component of asteroidal material. They are generally considered spherical, with the majority exhibiting aspect ratios ≤1.2. Leoville, a Vigarano-type carbonaceous chondrite, exhibits one of the most severe deformation regimes observed in chondritic meteorites. Potential causes of elongation include compaction through overburden and shock. Micro-CT enables non-destructive 3D analyses that provide new insight into the degree of deformation and direction of preferred orientation.

A 27mm x 25mm x 5mm sample of Leoville was scanned at 19 µm/voxel using a Nikon HMXST 225 system at the Natural History Museum, London. Segmentation was carried out in Avizo using manual outlining and interpolation. Shape analyses were completed in Blob3D through fitting ellipsoids to the segmented chondrules. Similar analyses were carried out on two regions of the scan to represent the two distinct lithologies present.

The average chondrule aspect ratio is 1.82 (n=52, σ=0.33), corresponding to uniaxial shortening of 65% or 52%, assuming constant volume and initial aspect ratios of 1.1 or 1.2 respectively. High aspect ratios favour shock over burial models for the cause of the deformation. Chondrule orientations in the two lithologies of Leoville are similar, indicating that deformation occurred after accretion. Consequently, the variation in aspect ratio may be due to compositional differences, and/or a result of matrix volume and porosity variation between the lithologies. Analyses of random slices in each orthogonal plane yielded aspect ratios varying from 1.25 to 1.76, indicating that deformation is consistently underestimated using 2D methodologies.

Automated multiscale 3D feature learning for segmentation of vessels in CT images of human lungs

Tomasz Konopczynski

Interdisciplinary Center for Scientific Computing (IWR), Heidelberg University, Berliner Str 43, 68120 Heidelberg, German Volume Graphics GmbH, Wieblinger Weg 92A, 69123 Heidelberg, Germany

Abstract

Please contact the author for more information: Tomasz.Konopczynski@medma.uni-heidelberg.de

Modelling volumetric errors due to angular detector misalignments in X-ray computed tomography

Massimiliano Ferrucci[1, 2] and Evelina Ametova[2]

[1] *National Physical Laboratory, Hampton Road, Teddington, TW11 0LW, UK*

[2] *KU Leuven, 3000 Leuven, Belgium*

Abstract

The assessment of uncertainty is critical for establishing confidence in dimensional X-ray computed tomography measurements. One method for evaluating measurement uncertainty is by the substitution or comparator method. In this method, the measurements of a test object are compared to the measurements of a calibrated reference object similar in shape, size, and material composition; conditions and settings are typically kept the same for both measurements. Studies have shown that the comparator method can be applied to estimate uncertainty using X-ray computed tomography. However, not all users have access to a calibrated reference object; therefore the comparator method is not suitable for their measurement needs. For this purpose, the GUM method is a possible alternative to assessing measurement uncertainty. In this study, the effects of angular misalignments of a detector in cone-beam CT are modelled. First, binning of radiographic intensities are mapped as pixel coordinate errors in the detector space. Then, the radiographic errors are backprojected to each voxel in the measurement volume at each rotation position of the stage. The backprojected volumetric errors are compared to observed volumetric deviations in the simulated scan of a reference object. Similarities between observed and modelled results are discussed and implications of the model on the assessment of CT measurement uncertainty by the GUM method are presented.

Developing baselines of coral skeletal growth and bioerosion from the Indian Ocean

Rebecca Summerfield[1], Erica Hendy[2], Kirsty Penkman[3], Kenneth Johnson[1]

[1] *Natural History Museum, Cromwell Rd, London SW7 5BD, UK*

[2] *University of Bristol, Senate House, Tyndall Ave, Bristol, City of Bristol, BS8 1TH, UK*

[3] *University of York, Heslington, York, YO10 5DD, UK*

Abstract

The Natural History Museum's collections include thousands of coral specimens collected from the Seychelles, Maldives and Chagos Archipelago in the 1960s and 1970s. Globally, monitoring of reefs was rare prior to the 1980s, so these collections provide an irreplaceable snapshot of the coral and the endolithic boring communities present on these reefs over 50 years ago. Here I will demonstrate how we are applying non-destructive three-dimensional computerized tomography (micro-CT) on complete coral colonies to obtain species-specific growth rates, identify epi- and endobionts, and quantify skeletal bioerosion rates from these specimens. Without this historic baseline data it will be impossible to show how processes and patterns have shifted in the recent period, to what we observe on Indian Ocean reefs today.

Comparison of different additive manufacturing methods using optimized computed tomography

Paras Shah, Radu Racasan, Paul Bills
The Centre for Precision Technologies, School of Computing & Engineering, University of Huddersfield, Queensgate, Huddersfield, West Yorkshire HD1 3DH, UK

Abstract
The optimisation of the computed tomography acquisition parameters for additive manufactured artefact presented in light of feature dimensions and form analysis. This poster investigates the accuracy and capability of CT measurements compared with reference measurements from a coordinate measuring machine (CMM), as well as focus on the evaluation of different AM methods.

Metrological Investigation of Scatter Filtration in X-ray CT

N. Kourra, J. M. Warnett, A. Attridge, M. A. Williams
Warwick Manufacturing Group, University of Warwick, Coventry, CV4 7AL, UK

Abstract
X-ray computed tomography (XCT) is a non-destructive evaluation method that is gaining interest in dimensional metrology applications. XCT utilises X-rays, collecting 2D radiographs that are then reconstructed to a 3D model that provide information about the specimen and assist with the characterisations of defects. This technology has the potential to provide information, unobtainable by other non-destructive, non-contact techniques. There are numerous factors that can affect the XCT results and increase their measurement uncertainty such as shift and changes of X-ray focal spot, geometrical alignment issues, environmental issues and the unpredictability of X-rays. One of the most common issues in XCT is beam hardening and scattered radiation that can result in artefacts and hence variation in dimensional measurements. This study investigates the effect of physical pre and post filtration on scattered radiation on dimensional measurements. Here, a calibrated specimen is used based on designs for ISO 10360-11 CT for dimensional measurements. The scattered radiation is measured for different copper filtering thicknesses placed before and after the scanned specimen and the resultant threshold depended measurements vary with the degree of scatter. The results provide information that assists the selection of filtration in order to reduce scattered radiation and improve dimensional measurements, while they demonstrate that post filtration should be considered when scanning specimens that generate large amounts of scatter.

3D visualization of Li-ion battery degradation using laboratory based X-ray microtomography

Romeo Malik[1], Donal Finegan[2], Oluwadamilola Taiwo[2], Melanie Loveridge[1], Paul Shearing[2], Rohit Bhagat[1]

[1] *Electrochemical Engineering Group, Warwick Manufacturing Group, University of Warwick, Coventry, CV4 7AL, UK*

[2] *Electrochemical Innovation Laboratory, Department of Chemical Engineering, University College London, Torrington Place, London, WC1E 7JE, UK*

Abstract

Li-ion batteries are the energy storage technology of choice for next generation automotive and grid storage applications. In recent years considerable studies have shown that crystalline silicon is a promising negative electrode candidate, with a specific capacity of 3579 mAh/g which is ca. 10 times the specific capacity of graphite. However, silicon still has major performance issues associated with the volume expansion which can result in cracking and pulverisation of active particles. Additionally the surface of the silicon reacts with the electrolyte at lower voltages to form the solid-electrolyte interphase (SEI) – a major source of continued irreversible Li loss. Subsequent charge-discharge cycling causes repeated disruption of the SEI layer where it continues to form and grow. These phenomena culminate in conductivity loss and capacity fade. This poor electrochemical stability of silicon anode is preventing it from commercialization. Despite the numerous studies and evolution of sophisticated in-situ characterisation techniques, relatively little is understood still about the microstructural evolution and its impact and relation to the cell performance during operation and failure. Therefore, a more detailed study is required to fully characterise types of crystalline silicon as well as the importance of electrode architectures for high capacity lithium-ion storage materials.

X-ray computed tomography (CT) has been proven to be an effective tool to explore the hierarchical structure of battery electrodes and for diagnosing battery failure mechanisms at multiple- length scales. X-ray CT, in conjunction with impedance spectroscopy and associated physical characterization, will be employed to capture and quantify key aspects of the evolution of internal morphology and resistance build up. This includes characterisation of SEI growth, porosity changes and conductive network breakdown during charge-discharge operation. This approach will enable us to observe and quantify failures in Li-ion batteries at the electrode level, and thus facilitate construction of better electrode architectures.

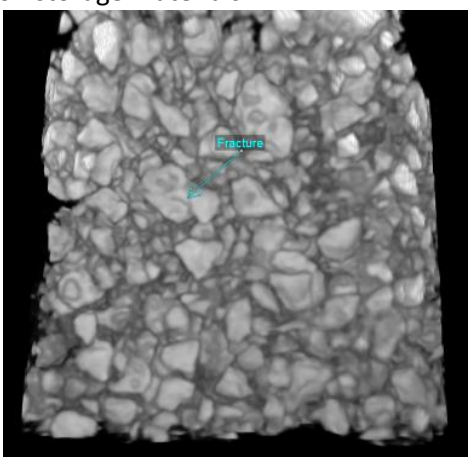


Figure 1: Reconstructed tomographic image (using Zeiss Xradia 810 Ultra) revealing a cracked particle in cycled silicon anode.

This study aims to investigate modes of degradation in composite silicon anodes for Li-ion battery operating under different aging time i.e. number of cycles of charge and discharge and comparing microstructural architecture with performance. This will enable better design and formulation of longer-lasting batteries.

An approach in quantification of the alveolar bone changes after dental implant placement based on 3-D CBCT images

Xiaoli Cheng, Lifong Zou, Alessia D'Onofrio, Nikos Mardas, Nikolaos Donos
Bart's and The London School of Medicine and Dentistry, Queen Mary University of London, UK

Abstract

Objectives: To establish a geometric measurement strategy quantifying alveolar bone changes around dental implant, through the CBCT images taken before and one year after implant placement. To measure and compare bone changes in parameters of thickness and height of clinical cases of Type 1 and Type 4 implant placements on premolar and molar sites, using the measurement strategy.

Methods: A 3D voxel image analysis software - OnDemand3D (US) was evaluated and used for image reconstruction, analysis and measurements of the bone thickness and height changes around the implant. 69 CBCT data sets (44 type 1 cases, 25 type 4 cases) were collected from CBCT database in Shanghai Ninth People's Hospital, China. NobelReplace Tapered Groovy system was used in all cases and bone grafting was applied if necessary. Four measurement sections were defined for bone thickness on lingual (L_0O_0, L_1O_1, L_2O_2, L_3O_3) and buccal side(B_0O_0, B_1O_1, B_2O_2, B_3O_3) which were on implant neck level and 1mm; 4mm; 7mm under the implant neck level.

Results: The largest bone thickness changes were found on L_1O_1 and B_1O_1. Among 44 paired type 1 implant CBCT data sets, the mean value of bone thickness change was 0.13mm (ranged from -2.40mm to 3.10mm) at L_1O_1 and -0.25mm (ranged from -3.08mm to 2.30mm) at B_1O_1. Bone height change on lingual side was 0.25mm (ranged from -2.30mm to 1.6mm) and that of buccal side was 0.18mm (ranged from -2.60mm to 4.2mm). In 25 paired type 4 data sets, the mean value of bone thickness change was 0.07mm (ranged from -0.7mm to 2.25mm) at L_1O_1 and -0.16mm (ranged from -2.09mm to 1.90mm) at B_1O_1. Bone height change on lingual side was 0.06mm (ranged from -1.00mm to 1.90mm) and that of buccal side was 0.10mm (ranged from -1.56mm to 28mm). No significant difference was found between Type 1 and Type 4 on each measurement section.

Conclusion: This study found no significant difference between the two patient groups of Type 1 and Type 4 implant protocols.

Investigation of the effects of off-focal radiation on dimensional measurements in cone-beam X-ray computed tomography

Nadia Flay[1, 2], Stephen Brown[1], Wenjuan Sun[1], Thomas Blumensath[2]

[1] *National Physical Laboratory, Hampton Road, Teddington, Middlesex, TW11 0LW, UK*

[2] *University of Southampton, University Rd, Southampton, SO17 1BJ, UK*

Abstract

The focal spot is defined as the area of the X-ray tube where the electron beam hits the surface of the target. In most applications of X-ray computed tomography (XCT), the focal spot is assumed to be one specific area. However, in real XCT systems, when the incoming electron beam impinges onto the surface of the target, backscattered electrons are produced; these backscattered electrons interact with metal surfaces other than the focal spot area, generating off-focal radiation. The off-focal radiation can subsequently give rise to unwanted 'secondary focal spot' phenomenon. In literature, off-focal radiation is also known as 'secondary', 'extra-focal' or 'parasitic' radiation. The exact characteristics of off-focal radiation may vary depending on the number and the direction of motion of backscattered electrons, distance from target to the tube housing, the geometry and material of the target and the housing, as well as the overall tube design. For example, in X-ray tubes with rotating anode, backscattered electrons are accelerated back towards the anode outside the focal spot area, causing low intensity X-ray emission over the entire anode area. Unlike X-ray tubes with rotating anode, in reflection type micro-focus X-ray tubes backscattered electrons are not accelerated back to the target. Instead they interact with the tube housing material, generating additional high-energy X-rays inside the tube structure, thus producing characteristic secondary images of scanned objects. The effects of off-focal radiation in X-ray tubes with rotating anode have been widely discussed in literature [1–3]. However, in micro-focus X-ray tubes, such effects are practically undocumented [4]. This novel study describes the origins of off-focal radiation in a cone-beam micro-focus XCT system, investigates the influence of off-focal radiation on dimensional measurement using computer simulations and proposes a simple technique for effective characterisation of off-focal radiation in a cone-beam micro-focus XCT.

[1] Behling R 2015 *Modern diagnostic X-ray sources: technology, manufacturing, reliability* (CRC Press)

[2] Ali E S M and Rogers D W O 2008 Quantifying the effect of off-focal radiation on the output of kilovoltage x-ray systems *Med. Phys.* **35** 4149

[3] Hsieh J 2009 *Computed tomography: principles, design, artifacts and recent advances* (SPIE Press)

[4] Boone M N, Vlassenbroeck J, Peetermans S, Loo D Van, Dierick M and Hoorebeke L Van 2011 Secondary radiation in transmission-type X-ray tubes : simulation , practical issues and solution in the context of X-ray microtomography *Nucl. Instruments Methods Phys. Re- 4 search Sect. A Accel. Spectrometers, Detect. As- 5 sociated Equip.*

CAD model reconstruction for electromagnetic field simulations by using computed tomography scans

J. Hillebrand, S. Kieß, K. Sun, S. Simon
Institute for Parallel and Distributed Systems - Parallel Systems Department, Universitätsstraße 38, 70569 Stuttgart, Germany

In this poster, computed tomography is proposed to analyse the electrical parameters of high-speed digital interconnects and planar microwave circuits. The method is based on the extraction of accurate simulation models from computed tomography scans. The models inherently comprises of manufacturing defects and variations from the investigated devices, which makes them suitable for their analysis by using simulations. Using appropriate CAD operations, regions of interest can be separated from the extracted models and analysed. This enables an analysis of the electrical parameters of devices which are located on inner layers of multi-layer circuit boards or are enclosed by IC packages and cannot be directly connected to conventional measurement equipment. Using the example of a BGA Package and a microwave hybrid coupler the basic principle of the method is described. Its accuracy is demonstrated by a comparison of measured S-parameters and simulated S-parameters. For the measurement a vector network analyser has been used. The simulation is based on an extracted CAD model of the measured hybrid coupler.

Organising committee

Conference Chair
Dr Michael McCarthy michael.mccarthy@npl.co.uk

Conference Co-Chair
Dr Wenjuan Sun wenjuan.sun@npl.co.uk

Conference Coordinator
Mrs Veronica Luttman veronica.luttman@npl.co.uk

Session Chair
Mr Stephen Brown stephen.brown@npl.co.uk

Event organising team events@npl.co.uk
Mr Roger Hughes
Miss Hannah Carter
Miss Abigail Stone
Mrs Shelley Sharma

Attendee List

Adam Thompson	University of Nottingham
Alan Clarke	TWI Ltd
Alex Attridge	WMG
Alex Ball	Natural History Museum
Alex Lyne	AWE plc
Amalija Horvatic	Faculty of mechanical engineering and naval arhitecture
Amin Garbout	Natural History Museum
Andrew Lodge	Rolls-Royce
Andy Harris	Red Bull Technology
Andy Smith	Instron
Angus Davidson	ALS Oil & Gas
Biserka Runje	Faculty of mechanical engineering and naval arhitecture
Bryan Edwards	STFC
Carl Willoughby	Red Bull Technology
Carsten Batz	YXLON International GmbH
Chrissie Prychid	Royal Botanic Gardens Kew
Damien Latron	3M
Dan Sykes	University of Manchester
David Bate	Nikon
David Eatock	Airbus
David Lang	Grainger & Worrall
Dean Edwards	ZEISS
Evelina Ametova	KU Leuven
Farah Ahmed	Natural History Museum
Gary Beech	Grainger & Worrall
Gary Stokes	MINI Plant Oxford
Georgios Liaptsis	TWI Ltd
Glenn Jones	Imperial College
Graham Topley	National Physical Laboratory
Hannah Corcoran	National Physical Laboratory
Ian Belding	Carl Zeiss Ltd
Ian Nicholson	TWI Ltd
Ian Sinclair	University of Southampton
Ignacio Artamendi	R&D Department
Igor Novak	Oprema-strojevi
James Kratz	University of Bristol
James Willcocks	Rolls-Royce plc.
Jay Warnett	University of Warwick
Jessica Opie	AWE plc
Jiri Sperka	Czech Metrology Institute
John Spratt	Natural History Museum
Joseph Lifton	University of Southampton
Kathryn Ford	AWE
Katie Smith	Advanced Composites Centre for Science and Innovation (ACCIS)
Lars Korner	University of Nottingham
Laura Pickard	University of Bristol
Leigh Connor	Diamond Light Source
Lifong Zou	Bart's and The London School of Medicine and Dentistry, QMUL
Malcolm Riley	BMW MINI
Martin Turner	University of Manchester
Massimiliano Ferrucci	National Physical Laboratory
Mathias Johansson	SP Technical Research Institute of Sweden

Mathilde Rousselle	ALS Oil & Gas
Matthew McKeown	MINI Plant Oxford
Michael Cunningham	Rolls-Royce Plc
Michael Hadland	Nikon Metrology
Michael McCarthy	National Physical Laboratory
Moataz Attallah	University of Birmingham
Nadia Flay	National Physical Laboratory
Nadia Kourra	University of Warwick
Nassr Al-Nuaimi King's	College London Dental Institute
Natasha Almeida	Natural History Museum
Nathanael Turner	The MTC
Neil Campbell	National Physical Laboratory
Neil Hickman	AWE plc
Nicholas Bazin	AWE plc
Nick Brierley	The Manufacturing Technology Centre
Nick Davies	De Beers Technologies
Olena Flys	SP Technical Research Institute of Sweden
Paras Shah	EPSRC CPT
Paul Bills	University of Huddersfield
Paul Morrell	AWE plc
Peter Huthwaite	Imperial College London
Peter McDonnell	BMW Manufacturing Ltd.
Peter Woolliams	National Physical Laboratory
Rebecca Summerfield	Natural History Museum
Richard James	AMRC with Boeing
Richard Leach	University of Nottingham
Richard Watson	AWE plc
Robert Atwood	Diamond Light Source
Robert Speller	University College London
Romeo Malik	University of Warwick
Sally Irvine	Diamond Light Source
Sarah Hainsworth	University of Leicester
Sav Chima	AWE
Sean Woodward	National Physical Laboratory
Shan Lou	Huddersfield University
Sheng Yue	North Star Imaging, UK
Simon Whitbread	Hamamatsu Photonics
Stephen Anderson	Renishaw plc
Stephen Brown	National Physical Laboratory
Steven Bosworth	Rolls-Royce
Sven Simon	University of Stuttgart - IPVS
Timothy Whiteside	AWE plc
Tom McCready	AMRC with Boeing
Tomas Zikmund	CEITEC BUT
Tomasz Konopczynski	Heidelberg University
Trevor Slade	Red Bull Technology
Tricia Wilson	National Physical Laboratory
Vincente Rivas Santos	University of Nottingham
Wenjuan Sun	National Physical Laboratory
XiaoLi Cheng	Bart's and The London School of Medicine and Dentistry, QMUL