CTLAB
X-ray Computed Tomography

BRNO UNIVERSITY OF TECHNOLOGY

NEWSLETTER
SPRING 2018

FOREWORD

Dear Readers and Friends,

I am pleased to introduce a new issue of our laboratory newsletter. Our microCT device GE phoenix v|tome|x L240 was upgraded by an installation of the new nanofocus X-ray tube and by replacing the detector. The new detector provides 100 µm pixel size and higher resolution. Besides that, in this issue, we would like to show you some possibilities of microCT use in forensic anthropology or in simulations of optical systems. The Education section focuses on the uncertainty of measurement and last but not least there is a brief description of our new publications.

Enjoy the reading!

Tomas Zikmund
Head of the laboratory

NEW POSSIBILITIES OF A CT ANALYSIS USE

Utilization of CT in Forensic Anthropology: MicroCT Examination of Cranial Gunshot Injuries

In collaboration with the Laboratory of Morphology and Forensic Anthropology (LaMorFA) of Masaryk University, the microCT analysis of bone samples was applied in a gunshot wounds research (Fig. 1). Our current project was aimed at exploring new options of the utilization of microCT data for the visualization and evaluation of bone tissue damage at a microstructural level. At the microscale, the damage is manifested in a form of small cracks (microcracks) which can be used for determining the type of injury and can be therefore utilized in forensic anthropology, forensic medicine and forensic (criminalistic) ballistics.

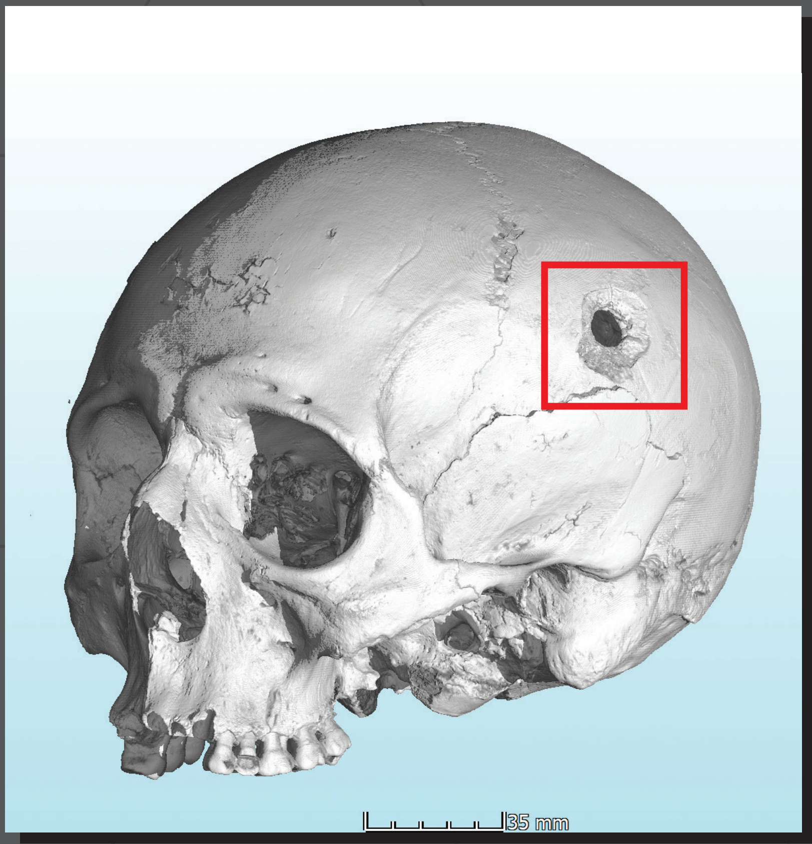

Fig. 1: 3D model of human skull with highlighted shot (measured on microCT GE phoenix v|tome|x L240).

Several bone samples were measured using microCT with several different resolutions (120 µm, 20 µm, 12 µm, 6 µm). For above mentioned purposes, the 12 µm resolution proved to be the most suitable since microcracks were well detectable and almost all their extent was captured. The microcracks were segmen-ted from the CT data using a combination of global thresholding and manual segmentation in Amira software. The creation of three-dimensional mo-dels enabled us to display the size, shape, accumulation and spatial distribution of the microcracks. The observed characteristics showed significant differences between the two analysed cases. In the first type of postmortem injury (after death), there was a small amount of extensive microcracks, radially propagating from the entrance wound (Fig. 2a). In contrast to this, in the second type of perimortem injury (at or near the time of death), there were more microcracks but their size (length and width) was signifi-cantly smaller. In this case, they were randomly scattered across the bone tissue (in all its various layers) (Fig. 2b). The results of this pilot study were presented at the 2017 IAFS international conference (Toronto, Ontario, Canada), http://iafstoronto2017.com/ in August 2017.

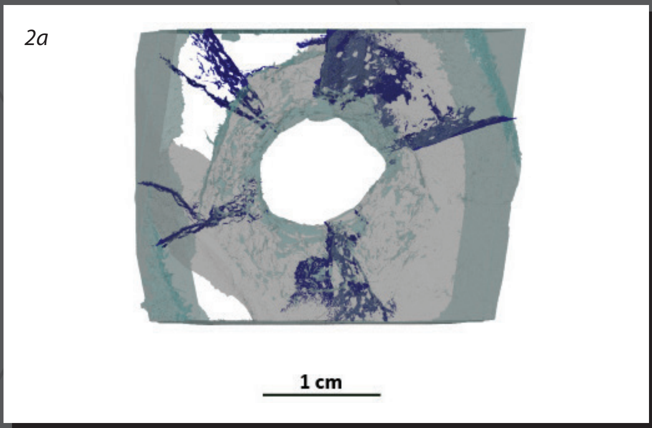

Fig. 2a: A 3D model of the sample with the first type of postmortem trauma showing the course of the microcracks (blue) in the bone tissue.

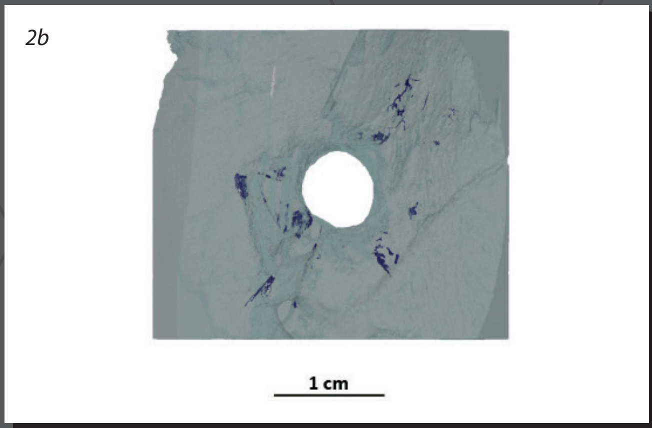

Fig. 2b: A 3D sample model with the second type of injury (perimortem) showing the course of microcracks (blue) in bone tissue.

Application of CT for simulations of optical systems

A detailed analysis of cameras' imaging modules in digital cameras of contemporary smartphones is one of the very interesting applications of microCT. This observation was provided by our colleagues from the Institute of Physical Engineering (Department of Solid State Physics and Surfaces) together with student Jakub Dokulil in the scope of Students' Professional Activities (SPA). The photo modules of several smartphones (Sony, iPhone, and Motorola) were scanned to identify their internal structure, i.e. the curvature of individual optical surfaces, their relative spacing and the dimensions of the scanning chip. The obtained data served as an accurate input for the subsequent simulation of optical systems.

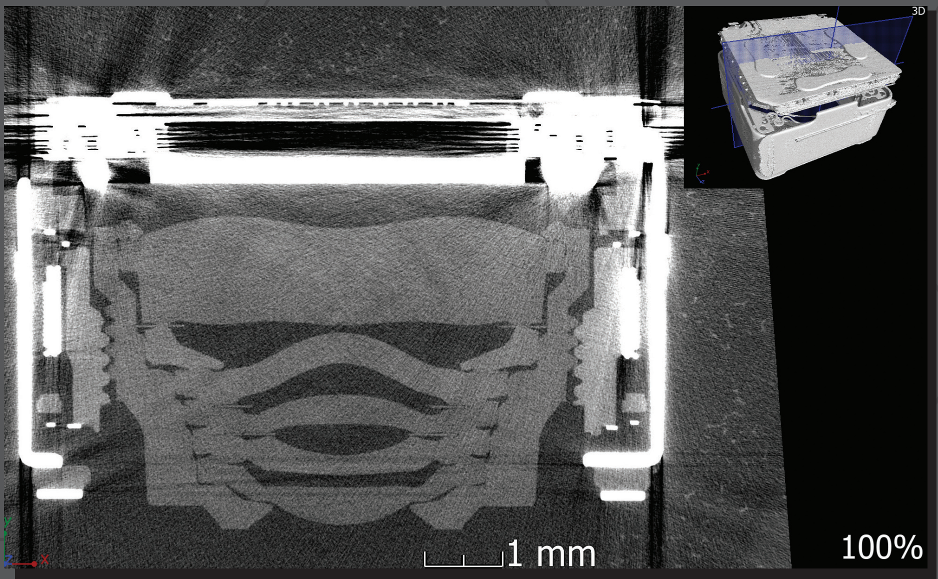

Fig. 3: A tomographic slice in the middle of the camera module from the selected smartphone.

The camera modules consisted of three to five plastic lenses forming an optical system with a focal length of approximately 4 mm. Most of the optically active surfaces were aspherical, one of them was of a similar shape as Schmidt's correction plate for correcting optical defects. The coordinates of the points forming the individual fragments were subtracted from the tomographic data and they were interleaved by a polynomial regression curve. Their coefficients were inserted into Zemax Optic Studio and the system was simulated for various imaging modes.

To achieve a successful simulation, it was important to specify the distances between the individual optical members and their width. Thanks to the CT analysis (Fig. 3) it was possible to analyze these small systems and their internal structure in detail before disassembling the individual optical elements. Otherwise it would not be possible to determine with a sufficient precision their mutual position.

Methods for a determination of measurements' uncertainties in computed tomography

Due to the technical progress, X-ray computed tomography (CT) can be used not only in the field of non-destructive testing but also in the field of dimensional metrology. The advantage of X-ray computed tomography is a possibility of measuring dimensions of inner features which are not accessible by the conventional optical or tactile coordinate measuring machines without a disassembly or destruction of the sample. The international standards describing the CT usage in dimensional metrology and determination of uncertainties are still in development, e.g. the German series of standards VDI/VDE 2630 [1].

The overall process of a CT measurement is complex and involves many factors, such as the ones related to the CT setup together with the influence of CT operator, as well as various properties of the sample under investigation (as is described in Fig. 4) In the CT data there may appear some image artifacts (beam hardening, scattering, metal artifacts…) which can radically worsen the possibilities of analysis [2].

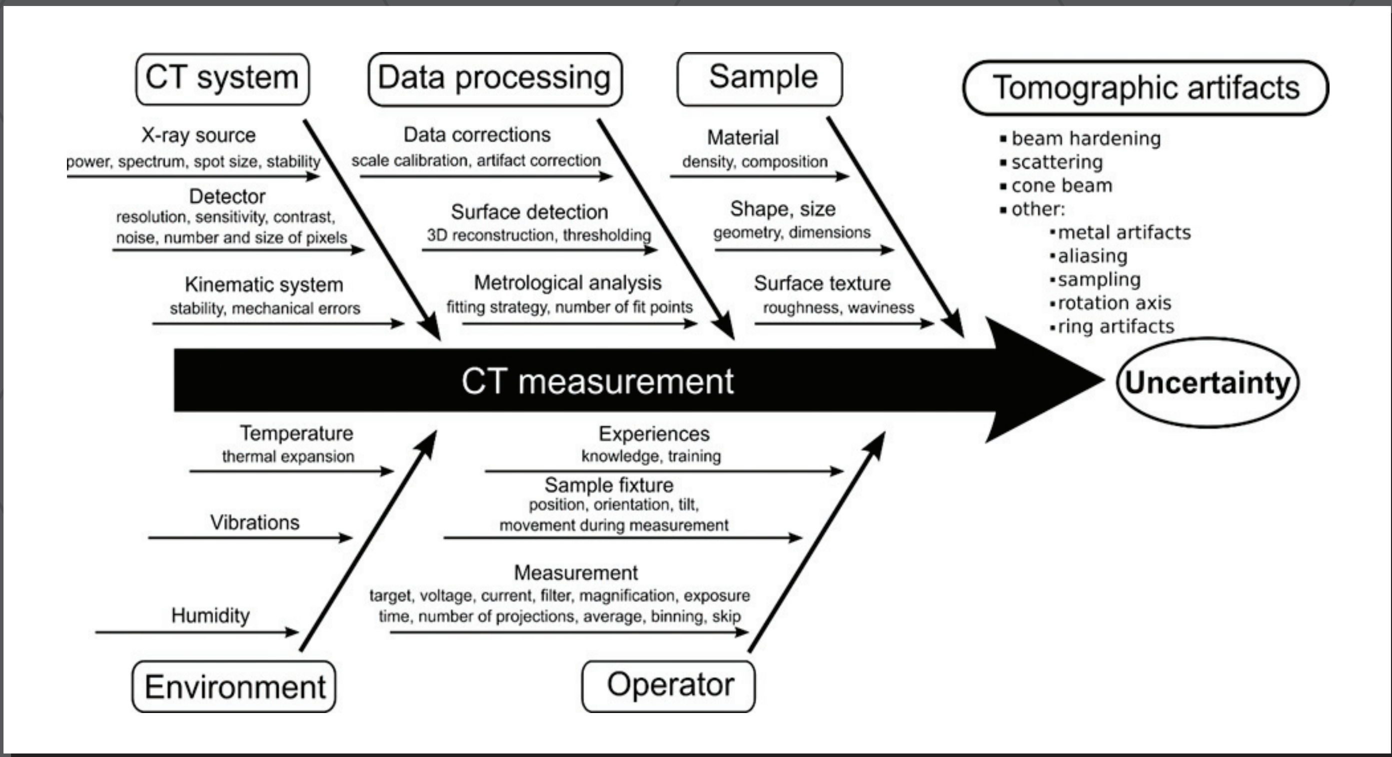

Fig. 4: Diagram shows the influence factors on CT measurement [4].

There are three methods to determine the measurement uncertainty:

» **Analytical methods** – the fundamental document describing the determination of uncertainties is Guide to the Expression of Uncertainty in Measurement (GUM) [3]. Measurement is described by a model function and the measured value is determined as the function of different inputs. The uncertainty of the inputs results in uncertainty of the measured value, which can be calculated by the law of propagation of uncertainty. Currently, there is not any exact and general analytical model of CT measurement which could be used applying this method.

- **Simulation-based methods** – an application of numerical Monte Carlo methods on dimensional metrology is described in documents Suppl. 1 to GUM (JCGM 101:2008), VDI/VDE 2617-7 and ISO/TS15530-4. Nowadays, there is software which can simulate the CT measurement (e.g. aRTist). However, a model which could fully cover all physical aspects and input quantities does not exist yet. Therefore, the use of these methods is still limited.

- **Experimental methods** – uncertainty of CT measurement is determined by a comparison of several CT measurements of a specific sample's dimensions with a reference measurement. This approach is described in the standard VDI/VDE 2630/2.1.[1] which is based on ISO 15530-3 for the determination of uncertainties on tactile CMM using calibrated workpieces.

Determination of uncertainties by experimental methods produces nowadays the most relevant results. First, the dimensions of the sample are determined using conventional methods, usually accurate tactile coordinate measuring machines. Then, several CT measurements are performed, and dimensions are determined. The determination of uncertainty of CT measurement is based on a statistical evaluation which includes the differences between a CT and CMM measurement. The disadvantage of this method is the necessity to perform several measurements on CT with the same settings. The VDI/VDE 2630/2.1. recommends at least 20 repeated measurements. This is very time-consuming and financially demanding so it is unattainable in practise.

Resources:

[1] VDI/VDE 2630-2.1, *Computed tomography in dimensional measurement – Determination of the uncertainty of measurement and the test process suitability of coordinate measurement systems with CT sensors,* 2012

[2] KRUTH, J. P., M. BARTSCHER, S. CARMIGNATO, R. SCHMITT, L. DE CHIFFRE and A. WECKENMANN. Computed tomography for dimensional metrology. CIRP Annals, 2011. 60(2), 821–842, ISSN 0007-8506.

[3] *BIPM IEC IFCC ILAC ISO IUPAC IUPAP OIML 2008 Guide to the Expression of Uncertainty in Measurement JCGM 100: 2008, GUM 1995 with minor corrections,* http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf

[4] VILLARRAGA-GÓMEZ, Herminso, ChaBum LEE a Stuart T. SMITH. Dimensional metrology with X-ray CT: A comparison with CMM measurements on internal features and compliant structures. Precision Engineering, 2018. 51, 291–307. ISSN 0141-6359.

PARTICIPATION/NEW PUBLICATIONS

iCT 2018 Conference

8th Conference on Industrial Computed Tomography was held in Wels, Austria from 6 to 9 February 2018. This conference was organized by the Computer Tomography Research Group (www.3dct.at) at the University of Applied Sciences Upper Austria. It is the largest international conference on industrial computed tomography in Europe. During the conference, the latest products of tomographic equipment manufacturers and software for the processing of tomographic data are presented. Selected conference papers can be found here: http://www.3dct.at/cms2/index.php/en/conference-proceedings. Next year, this conference will take place in Padua, Italy.

New publications

The publication: High-contrast differentiation resolution 3D imaging of the rodent brain by X-ray computed microtomography (https://doi.org/10.1088/1748-0221/13/02/C02039) is focused on the imaging of mouse brain by micro computed tomography and it was published in the Journal of Instrumentation. It describes the whole process from the sample preparation, measurement and the subsequent processing of tomographic data. The preparation of the sample is described in detail, especially the application of various contrast agents. As far as data processing is concerned, the way of segmentation and the subsequent visualization of different internal structures of the brain is proceeded. The comparison of CT data with the magnetic resonance method is also included.

Our Rigaku nano3DX device was used for a visualization of biodegradable cryogels, the experiment is described in this publication: Chondrogenic potential of macroporous biodegradable cryogels based on synthetic poly (a-amino acids) (DOI: 10.1039 / c7sm02074k) published in the Soft Matter journal. Here, the morphology of two samples of highly porous hydrogels based on biodegradable synthetic polyamino acids was observed by the nanoCT. From the CT data, the pore volume of the cryogels was subsequently analysed. Then, the size and distribution of the cryogels was determined.

Together with our colleagues from the Elettra synchrotron in Italy we prepared this publication: Comparison of Different Experimental Approaches in Tomographic Analysis of Ancient Violins (DOI: 10.1016 / j.culher.2017.02.013) which aims to compare different experimental approaches of X-ray computed tomography in an analysis of ancient violins. The article is a part of a special issue of Journal of Cultural Heritage, dedicated to the analysis of wooden musical instruments. Here, measurements of the violin from medical CT, laboratory CT and CT on the synchrotron are presented and the results are evaluated. The article describes various experimental configurations of CT devices and compares their parameters: acquisition time, flexibility, spatial resolution or data set.

Upgrade of the microCT station GE phoenix v|tome|x L240

The equipment of our laboratory has to be kept in perfect condition in order to keep producing top quality data. Therefore, we regularly update software and we buy high-performance computer stations or special mounting tools. This spring we performed a massive upgrade of our CT station GE phoenix v|tome|x L240. This included a replacement of the detector and nanofocus X-ray tube. Both of these new components will allow us to obtain CT data with even better contrast and voxel resolution. The full advantage of this update is expected to be taken especially for polymers, aluminium alloys and also biological tissues.

Dynamic 41|100 detector

The installation of the new X-ray detector dynamic 41|100 [1] is definitely the most important change of our microCT device. Compared to the old detector, the new one was developed especially for industrial applications, which is taken into account, for example, in protecting the electronics from the X-ray. The new detector is more sensitive and it has half size of the pixels (100 x 100 µm) than the old one. Since the size of the detector remained the same, the total amount of the pixels is four times bigger, i.e. 4048 x 4048 px. Smaller size of the pixels allows to reach twice better voxel resolution within the same sample size (with respect to the X-ray absorption of the sample). Higher sensitivity will help us to obtain data with better contrast or to reduce the acquisition time eventually (Fig. 5).

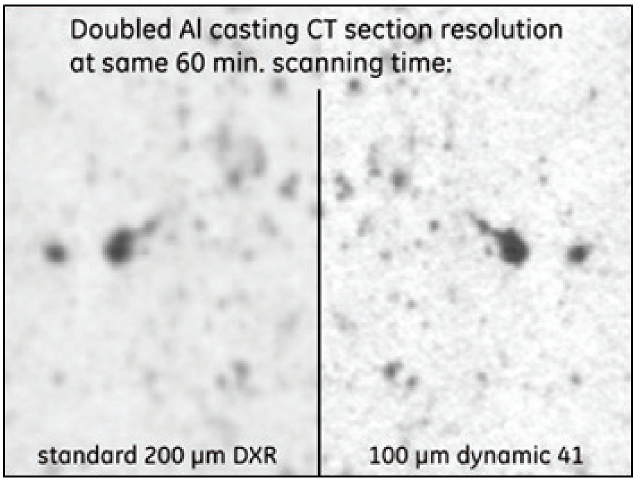

Fig. 5: Tomographic cross section of the aluminium casting, showing the differences between the old and the new detector (picture provided by GE).

[1] https://www.gemeasurement.com/inspection-ndt/radiography-and-computed-tomography/dynamic-41100-superior-image-quality-x-ray-detector

Liquid cooled 180kV – tube

Another recent innovation is the installation of the new nanofocus X-ray tube (see Fig. 6). It is the newest generation of this tube, equipped with liquid cooling. This helps to eliminate the movement of the focal spot and to reach homogenous irradiation of the sample and more stable tube conditions. Therefore, the effect of the liquid cooling will be proven especially for longer exposure times. Furthermore, the target material (tungsten or molybdenum) can be changed on this tube. This influences the radiation spectrum of the X-ray. This feature will be used especially for the visualisation of light materials or for some advanced methods such as dual energy tomography or the phase contrast.

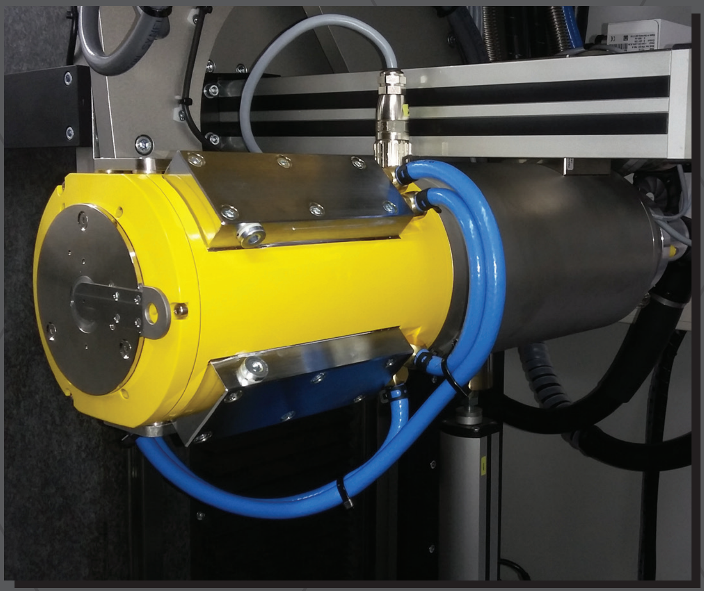

Fig. 6: New nanofocus X-ray tube.

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