CALIBRATION OF COMPUTER TOMOGRAPHY SYSTEM BY APPLYING PHOTOGRAMMETRY APPROACHES

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ABSTRACT
Geometric distortions cause by the acquisition process and the imaging device leading to geometrical inaccuracies of any quantitative and qualitative measurement and analyse in the image. In computer tomography distortions will also affect the mathematical reconstruction algorisms and introduce artefacts in the reconstructed volume image. The correction of x-ray projection is a key issue and requirement for the use of tomography data.

1. INTRODUCTION

Computer tomography is a non-destructive imaging technique for visualising structure and properties of solid objects and for obtaining information on their three-dimensional geometries and topology. In opposite to closed range photogrammetry, computer tomography looks inside the object and analyze processes under its surface. It can be used for a wide range of materials including metal, bone, ceramic and with reservations bio-material. This volume imaging technique was originally developed for medical application and is nowadays also used for material research. But it differs from conventional medical scanning methods in its ability to resolve very small details down to a few micrometers in size even when the sample object is made of high density materials.

The Institute of Photogrammetry and Remote Sensing (IPF) cooperates with the Institute of Materials Science (IfWW) of the University of Technology Dresden in the field of measuring and analysing computer tomography image data of material samples. The experiments shown in this paper are carried out on a cone beam tomograph at the TU-Dresden and on a synchrotron at the BESSY in Berlin (Fig. 1). The tomograph can be operated with maximal 225kV and penetrates even through 8cm blocks of concrete. With the 1024x1024 CCD sensor it is possible to image an object with a resolution up to 2µm respectively 2 mm object size. But the typically sample size is around 5-10 mm and results a resolution between 5 and 10 µm. The synchrotron in Berlin can operate with two fix resolution 1.5 and 3 µm which allow a maximum object space of 3 an 7 mm. The used CCD camera has a resolution of 2048x2048.

Applying photogrammetric image analyzing techniques and extended or adapted them to three-dimensional voxel-data material parameters can be derived automatically from multi-temporal data sets. To overcome the border of image resolution subvoxel image analyzing techniques have been developed and achieved an accuracy better than 1/10 voxel. To ensure subvoxel exactness imaging process and image data must be free of distortions adjusted of artefacts. In computer tomography distortions will also affect the mathematical reconstruction algorisms and introduce artefacts in the reconstructed volume image. The correction of x-ray projection is a key issue and requirement for the use of tomography data.

Figure 1: (a) cone beam tomograph (IfWW TU-Dresden), (b) synchrotron (BESSY Berlin)

2. COMPUTER TOMOGRAPHY

In conventional radiography, X-rays passes through the investigated object, and the transmitted intensity is recorded as a two-dimensional image. The attenuation of the x-ray by interacting with the material is the fundamental parameter and the actual measurand value of this method. If the sample is imaged several times in different orientations, three-dimensional volume information on the sample structure can be obtained by using computer algorithms. The result is a volume image where the single elements (voxel) represent the local abortion respectively the attenuation coefficients. So you see the density allocation and not colour or reflection variations. Object with the same or similar abortion behaviour can not be divided with computer tomography (Pratt 1978, 1).

“Tomos” is the Greek word for “cut” or “section” and “graphy” the word for “writing something”, so that tomography describes a technique for digitally cutting an object using X-rays to reveal its interior details. A computer tomography image is typically built on slices, like slices of bread. This analogy is suitable because just as a slice of bread has a thickness, a computer tomography slice corresponds to a certain thickness of the object being scanned. Therefore whereas a typical digital image is composed of pixels (picture elements), a computer tomography image is composed of voxels (volume elements).

The grey levels in a computer tomography slice correspond to X-ray attenuation, which reflects the proportion of X-rays scattered or absorbed as they pass through each voxel. X-ray attenuation is primarily a function of X-ray energy and the density and atomic number of the material being imaged. A computer tomography image is created by directing X-rays through the slice plane from multiple orientations and measuring their resultant decrease in intensity. A specialized algorithm is then used to reconstruct the distribution of X-ray attenuation in the slice plane. By acquiring a stacked, contiguous series of computer tomography images data describing an entire volume can be obtained in much the same way as bread can be reconstructed by stacking all of its slices (Fig. 2).

After this measuring technique was developed in medicine applications for imaging soft tissue and bone X-ray computer tomography was subsequently extended and adapted to a wide variety of industrial tasks. Because industrial computer tomography systems image only non-living objects, they can be designed to take advantage of the fact that the items being studied do not move and harmed by X-rays. The use of higher-energy X-rays, which are more effective at penetrating dense materials and smaller X-ray focal spots, providing increased resolution and longer exposure times increasing the signal-to-noise ratio.

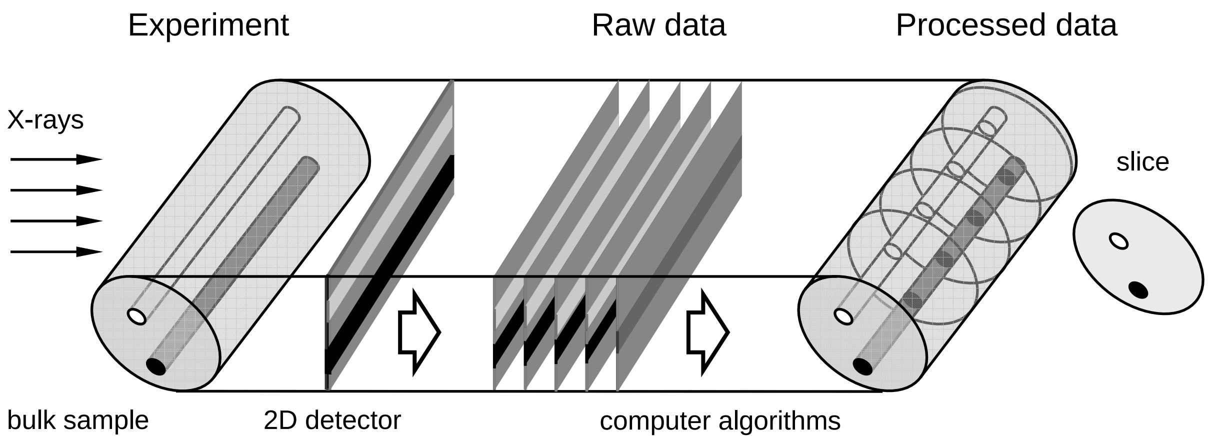

Figure 2: Prinziple of computer tomography

The only preparation that is absolutely necessary for computer tomography scanning is to ensure that the object fits inside the field of view and that it does not move during the scan. Because the full scan field for computer tomography is a cylinder the most efficient geometry to scan is also a cylinder. Thus when possible it is often advantageous to have the object take on a cylindrical geometry, either by using a coring drill or drill press to obtain a cylindrical subset of the material being scanned, or by packing the object in a cylindrical container with either X-ray-transparent filler or with material of similar density. Because the contrast mainly depends on density for some applications the sample has to be treated to enhance the contrasts. Coating with high density materials (gold and copper) and placement with copper balls are examples of marking the object structure.

3. CALIBRATION

Uncertainty and inaccuracy are a part of every measurement and can not be neglect or ignore in general cases. These errors consist of a rough, statistic and systematic component. The rough errors should be an exception and have to avoid and eliminated by a specific setup and controls. Statistic errors care an accidental phenomenon that can not be avoid but reduced by multiple measurement. Systematic errors are cause by the used measurement method and the devices. This last error can be reduced or eliminated by calibrating and correcting the measurement system. In computer tomography calibrations are necessary to establish the characteristics of the X-ray signal as read by the detectors under scanning conditions, and to reduce geometrical uncertainties.

3.1 Radiometric calibration

The reconstruction of a three-dimensional density distribution requires data on the X-Ray attenuation of all pixels of all projection images. To compute the attenuation during the reconstruction the ratios of the intensities measured with and without specimen are required. To perform the calibration an X-Ray image (reference image) I_{ref} is acquired, before the specimen is placed in the optical path (Herman 1990, 2). The superposition of noise and image data has to be considered when the calibration is performed. The noise in the reference image would cause systematic errors of the attenuation images and a reduction of noise in the reference image is required. To achieve this goal we acquire a series of reference images and combine them in an average reference image. The average calculation is preformed in the way that rough pixel errors are detected and dismissed form the average and do not influence the mean pixel value. The required corrected data are obtained by dividing the projection images by the reference image. To reduce the so call black noise of the camera a dark image I_d without x-ray intensity is subtract form the reference and object image. The radiometric calibrated image $I_c(\sigma)$ for a recorded object image $I_{obj}(\sigma)$ is given by the following equation:

$$I_c(\sigma) = \frac{I_{obj}(\sigma) - I_d}{I_{ref} - I_d} \tag{1}$$

With this correction the irregular intensity and sensitivity of the camera pixel, the variation of the scintillator and image intensifier as well as the inhomogeneity of the x-ray source are reduce. But non-regular variation during the imaging process or non-linear effects will still remain appear as ring and comet artefacts in the image of the sample. There are different approaches of reducing or eliminating ring artefact, the most promising correct direct the projections in the sinogram space. While Raven (Raven 1998, 3) is using the Fourier transformation to removal the ring structure, Boin (Boin, Haible 2006, 4) is projecting the sinogram in one average profile and deleting the rings with a "Moving Average Filter". Both Methods tend to overcompensate the ring structure and cause a lost of the fine image information due to Fourier and the "Average Filter".

3.2 Geometric calibration

Geometric image distortions leading to geometrical inaccuracies of any quantitative and qualitative measurement or analyse in the image. These systematic errors are caused by the acquisition process and the imaging device. A radial and sigmoidal variation in image scale is characteristic for distortion and dislocations of more than 5-10 % of image size are not unusual. Tomography based on analogue x-ray film, the distortion is mainly introduces during the develop process of the film. Today the digital imaging chain causes more complex distortion behaviour. The imaging process of a computer tomography system in general can be described as follows. After transmitting through the sample object the X-rays are converted into visible light by a scintillator. An optical prism or mirror is used to deflect the light and bring the CCD-camera out of the direct X-ray beam. The image deformations are cause mainly by distortion of scintillator and camera lens system and adjustment of prism, mirror and camera.

Because a single and separated calibration is rather impractical a complete system calibration is carried out. Further the influence and the interaction of single distortion and deformation are unknown a polynomial approach is chosen as calibration equation to determine all effects in one step. For that purpose different calibration objects (Fig. 3) were developed and tested to determine the distortion parameters. The correction is modelled with polynomial grad 4 to 6.

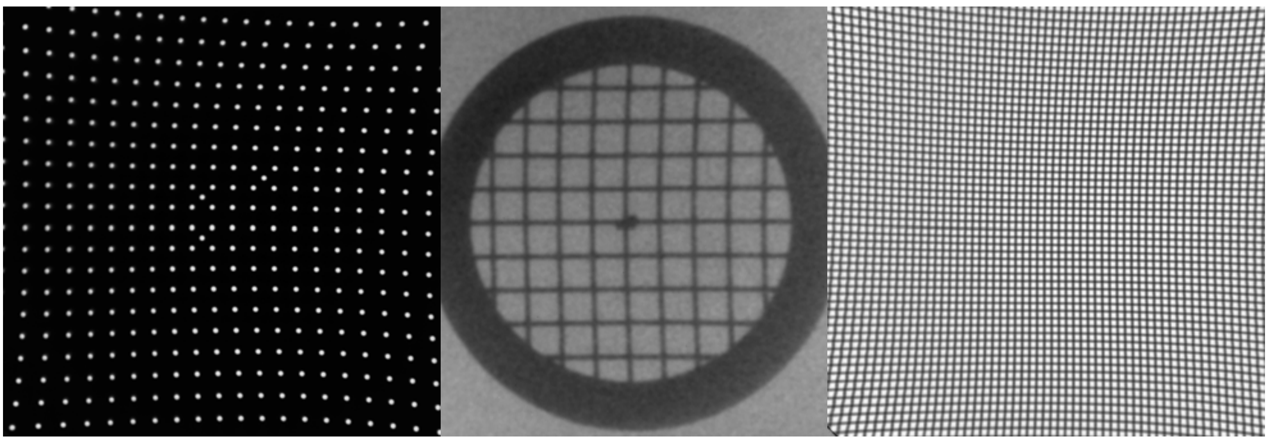

Figure 3: Calibration objects a: grit (3x3 mm), b: board (300x300 mm) and c: grit (10x10 mm)

The features of the use calibration object and the achieved accuracy are shown in the table below.

calibration object	size [mm]	points	m0 [pixel]
a : grid	3x3	82	0.11
b : board	300x300	393	0.07
c : grid	10x10	3080	0.04

The result of the rectification with the 10X10 grid (c) is presented in Fig. 4. The accuracy of the two-dimensional projection is verified with a calibrated line sample, where the mean error of the line size was determine with 0.05 pixels.

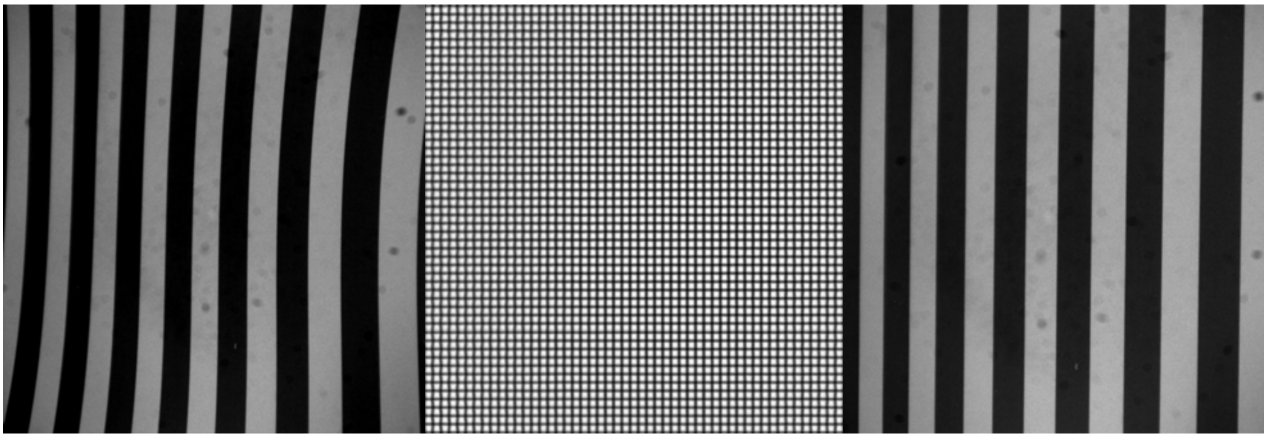

Figure 4: Verification with a calibrated line sample a: distorted image, b: rectify reference and c: rectify image

3.3 Correction of the rotation axis

The mathematical base of the computer tomography is the Feldkam algorithm and the Radom transformation witch transforms the projection into a three-dimensional volume. To calculate the volume correctly the projections have to be free from distortions and the rotation axis of the imaging process has to been an exact vertical line in the centre of the projection. The rotation axis is for the reconstruction process from greatest importance, even small deviation cause error and artefact in the superposition of projections from different rotation angle. An example form a dejusted sample and the effect are shown in Fig. 5.

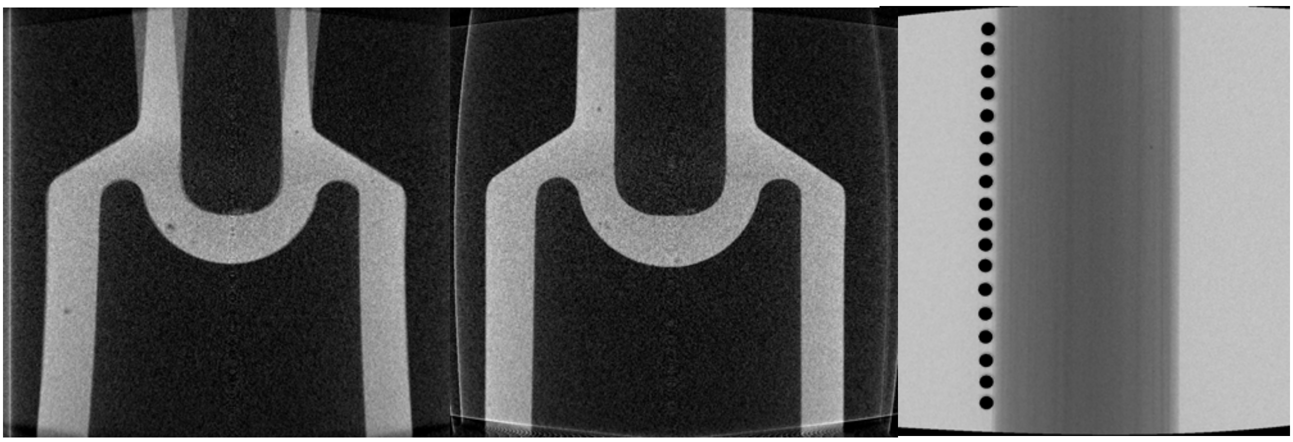

Figure 5: (a) dejusted and (b) correct sample slice along the rotation axis, (c) calibration object

To determine the parameters of the vertical and centred rotation axis a calibration object (Fig. 5) was use which consisted of metal balls. While this object is rotating the balls describe an elliptical path. The parameters of the estimated ellipse give the rotation axis.

4. RESULTS AND CONCLUSION

In this paper we discuss the possibilities of micro focus computer tomography in materials research joined with voxel-based photogrammetry. In this large interdisciplinary field of non-destructive testing methods not only high quality three-dimensional images of the internal structure of the material can be obtained or is of interest. Furthermore quantitative and metric information can be determined with photogrammetric image analysing techniques. Several examples have been pointed out and are subject of present research projects at the Technical University Dresden.

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