

The micro-CT scans of two Zutphen Early Iron Age Glass Beads Metadata

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Abstract:

This report gathers the meta-information of the X-ray micro-CT scans of two Zutphen Early Iron Age glass beads realised at TUDelft in 2011. First the equipment used for acquiring the scans is mentioned and dates of the scans are given. Then, the way the delicate beads were immobilized during scanning is indicated. Afterwards, the parameters for acquiring the scans and reconstructing the beads are documented. Measures taken (or not) to reduce artefacts that are inherent to X-ray micro-tomography are indicated. Steps followed during the processing of the reconstructed data are explained. In the conclusion, possibilities for re-exploiting the raw and reconstructed data of the beads are suggested.

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1. Equipment and dates of scans

Glass beads 1 and 2 were scanned by Ing Willem Verwaal at the Geoscience and Engineering Laboratory of Delft Technical University using the Phoenix Nanotom S (Zacher et al., 2011) manufactured by General Electrics. The scans were recorded on 21 February and 17 March 2011. Then, the Nanotom was equipped with a phoenix X-Ray 180 kV beam, a tungsten on beryllium target, and a 2300 x 2300 pixels HCD 120-50 detector.

2. Bead fixation during scanning

The beads are delicate objects. Supporting them during scanning by inserting a rod into their shaft or fixing them with adhesive tape would damage them. Instead, the beads were secured inside a 6 mm diameter plastic straw and immobilized with soft paper. The straw was fixed with glue and strong tape on top of a glass rod. The glass rod was locked in the mechanical jaws of the rotating platform of the Nanotom.

First Bead 1 and 2 were scanned together, with Bead1 laying vertically on top of Bead 2 that was laying horizontally. As the X-ray beam penetrated through various glass thicknesses during the rotation of Bead 1, the scan of Bead 1 is marked by an artificial anisotropy. Bead 1 was re-scanned separately while laying horizontally in an attempt to reduce disturbance.

3. Scanning and reconstruction parameters

For the first scan, a tube voltage of 85 kV and a tube current of 120 mA were used. 1440 projections were recorded over 360°, with an exposure time of 500 ms per frame. 5 frames were averaged and one frame was skipped per projection. This resulted in a total time scan of 1 hour 12 min. The highest spatial resolution of the Nanotom depends on the sample size, the spot size of the x-ray detector and the resolution of the detector. It is about 0.0005 mm. For the first scan, a resolution of 0.005 mm was obtained in all directions.

For the second scan, Bead 1 was scanned horizontally with a tube voltage of 65 kV and a tube current of 170 mA. 1440 projections were recorded over 360°, with an exposure time of 750 ms per frame. 5 frames were averaged and one was skipped per projection. This resulted in a total time scan of around 1 hour 48 min. For the second scan, a resolution of 0.003 mm was obtained in all directions.

The `datosx_acq.exe` version 1.3.3.6. software was used for scanning. Scan parameters for Bead 1 and Bead 2 are listed in table 1, Appendix A. After scanning, the `datosx_rec.exe` version software was used to combine the projections and reconstruct the beads in 3D. The file folders and names relative to the acquisition of the scans and the reconstruction of the scanned objects are listed in tables 2 and 3, Appendix A.

4. X-ray artefacts

Next to the artificial anisotropy discussed above, other artefacts such as beam hardening, streak artefacts, ring artefacts, and edge diffraction effects are visible in the reconstructed objects. Tarplee (2011) can be consulted for background information about X-ray μ CT artefacts and their mitigation.

In the first scan, a 0.1 mm thick Cu filter was used to reduce beam hardening. No physical filter was used for the second scan. A correction was applied during reconstruction to attenuate beam hardening in both scans (table 1). Some beam hardening is still visible after correction. Metal inclusions that are spread within the glass mass of the beads generated streak artefacts. The streak artefacts have not been corrected for. Ring artefacts caused to defect detector pixels were attenuated by shifting the detector during scanning. Remaining ring artefacts are due to beam hardening.

5. Post-processing

After reconstruction of the objects, a series of horizontal cross-sections was obtained and processed with the commercial software AVIZO, version 8.1.1. Alternatively, the scans can be analysed with the Open source software Fiji® (<http://fiji.sc/Downloads>) that is described in (Schlindelin et al. 2012).

The scans of Bead 2 were processed as follows:

1. The scans were denoised with a MEDIAN FILTER 3D.
2. The denoised scans were cropped and edited with VOLUME EDIT to discard the bead physical support and concentrate on the scanned object.
3. The reduced scans were thresholded using INTERACTIVE THRESHOLDING to select all solid materials: glass mass, minerals and metal inclusions as well as small impurities surrounding (but not touching) the bead.
4. The impurities were discarded by applying LABEL to the thresholded image and sieving out all small objects using FILTER.
5. The voids contained in the label image of the solid forming the beads were closed using CLOSING (3D neighbour 26, pixel size 60).
6. VOLUME FRACTION was applied to the closed volume to determine the total volume (solids plus inner bubbles as well as bubbles outcropping at the outside of the bead or at the shaft of the bead).
7. The reduced scans were masked (MASK) with the closed volume to discard in the analysis of voids the domains that surround the bead and represent the shaft of the bead.
8. The masked reduced volume was thresholded to select the voxels representing the voids contained inside the glass mass.
9. VOLUME FRACTION was applied to determine the volume of voids contained in the bead and calculate the bead porosity, knowing the total volume of solid contained inside the bead.
10. The thresholded image of the voids was analysed to extract the morphometric parameters of each individual filtered void using INDIVIDUAL LABEL ANALYSIS.
11. The labelled voids with an EQUIVALENT DIAMETER less than twice the voxel size (0.010 mm) were considered as noise and sieved out using the Excel SORT DATA function.
12. The voids contained within the bead consist of gaps delineating mineral inclusions, almost spherical air bubbles, partial air bubbles outcropping on the inner and outer surfaces of the beads, and bubbles connected to adjacent voids. The almost spherical air bubbles were selected in Excel based on their low ANISOTROPY ($ANISOTROPY < 0.3$) and subjected to a size analysis.

13. Masked reduced volume was also thresholded to analysis the metal and mineral inclusions within the glass mass.

A similar procedure was followed the scan of Bead 1. As the level of noise differs in the two scans and the grey levels representing the X-ray attenuation have not been calibrated, comparing quantitatively the results of the morphometric analyses of the bead constituents is not straightforward.

The video named bead 1 and bead 2-v3.MPEG 4 is stored in the 3TUdatacentrum to illustrate the way the data have been visualized, processed and interpreted.

6. CONCLUSION

This report documents the conditions under which the scans of the two Zutphen Early Iron Age beads were acquired, processed and post-processed. The data sets stored in the 3TUdatacentrum constitute a form of virtual preservation of the ornaments. The raw data can be reconstructed again with more advanced reconstruction softwares even if efforts still have to be made in terms of calibration of the whole micro-CT system in order to optimize the re-processing of raw data sets. The reconstructed scans can be further exploited by various stakeholders. Examples are given below.

Archeologists can consult our open-source virtual collection for a visual comparison of artefacts or a quantitative analysis of their morphometric parameters. This will enhance the understanding of various aspects of our cultural heritage such as intra-cultural exchanges along ancient trading routes.

The creative industry interested in reviving old local jewelry styles and capturing cultural diversity in Europe can use our virtual collection as source of inspiration.

Musea can display in their showrooms 3D animations of the ornaments that are too small to attract the attention of visitors. They can produce from the mesh of the inner and outer surfaces of the micro-CT models semi-transparent multi-colour 3D prints of the ornaments. The replicas can be manipulated by visitors for a better understanding of the art of making glass and jewels. Together with the gaming industry, musea could develop for their young visitors educative games based, for example, on pattern recognition intra- or inter-collections of scans. They can also include the scans in the digital reconstruction of archaeological sites at several scales.

REFERENCES

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APPENDIX A Tables

Table 1. Scan parameters for Bead 2 (scanned together with Bead 1) and Bead 1, scanned separately.

Table 2. List of archived for Bead 2(scanned together with Bead 1)

Table 3. List of archived data for Bead 1, scanned separately

Table 1. Scan parameters for Bead 2 (scanned together with Bead 1) and Bead 1, scanned separately.

Object	Units	Bead 2 (and Bead 1)	Bead 1
Scan number		1	2
Scan date	day-month-year	21-02-2011	17-03-2011
Bead position		horizontal (vertical)	Horizontal
Position detector	mm	200	200
Position sample	mm	18	12
Magnification	-	11.11	16.67
scanned volume	mm x mm x mm	11.42 x 11.42 x 11.52	6.85 x 6.85 x 6.91
reconstructed volume	mm x mm x mm	6.82 x 7.26 x 5.18	5.46 x 5.53 x 3.00
voltage	kV	85	65
Electron beam current	mA	0.120	0.170
Focal spot size	Mode	mode 0	mode 0
voxel size	mm	0.005	0.003
Physical filter	mm	0.1 Cu	-
Angular increment	degree	0.25	0.25
Number of images for	-	1440	1440
Average number of frame	-	5	5
Skipped frame	-	1	1
Scan time for one frame	S	0.50	0.75
Total scan time	hr:min:s	01:12:00	01:48:00
Numerical beam hardening correction	-	4.0	9.3
Denoising after reconstruction before processing with AVIZO		No	No

Table 2. List of archived for Bead 2(scanned together with Bead 1)

Bead 2	Scan 1	Date of scan	21-02-2011	
		Date of reconstruction	22-02-2011	
Folder	Ringen			
File	File extension	File content	File name	Size (Mb)
	HIS	Calibration of ambient radiation without object made at 3 different beam currents for a 500 ms projection time	ringen_MultGain_500ms_3p_1Det_	31.105
	HIS	Calibration of geometric of the system alignment for a 500 ms projection time	ringen ring_offset_500_	10.369
	IrfanView Raw file	Detector set-up	DefPix_L0	20.556
	IrfanView Raw file	Detector set-up	DefPix_L1	20.556
	TIFF	Detector set-up	DefPix_L2	10.297
	PCA	Scan parameters	Ringen	0.003
	PCP	System position during scanning	Ringen	0.122
	TIFF	Raw projections	ringen0001 to ringen1441	10.279 x 1440
	TEXT document	Timing of reconstruction process for Beads 1 & 2 and Bead 2 only	ringen no beam hardening correction ringen 2 bh 40 bh 40= beam hardening 4.0	0.008 0.008
	PCR	Reconstruction parameters for Beads 1 & 2 and Bead 2 only	ringen ringen 2 bh 40	0.001 0.002
	VGI	Reconstituted head file for Beads 1 & 2 and Bead 2 only	ringen ringen 2 bh 40	0.002 0.002
	VOL	Reconstituted volume of Beads 1 & 2 and Bead 2 only	ringen ringen 2 bh 40	2251.772 4007.475
	VGL	Reconstituted head file for Volume Graphics for Bead 2	ring 2 bh 40	0.014
Subfolder	[vg-project]	ring 2 bh 40		1.06
	VGP	Files for visualisation with Volume graphics for Bead 2		
Subfolder	ring 2 big bh 4			4008.284
Files	IrfanView DCM	Reconstituted horizontal (XY) orthoslices of Bead 2	ring 20000 to ring 21034	3.869x1036

Note: The scanned objects are “beads” and not “rings”. They have been wrongly named “ringen” during scanning and reconstruction. Bead 1 is smaller than Bead 2 and has been named small ring. Bead 2 was scanned together with Bead 1 in the first scan. The first scan has been named “ringen”. The reconstruction of Bead 2 only has wrongly been named “ringen 2 bh40”. It should have been named “ring 2 bh40”.

Table 3. List of archived data for Bead 1, scanned separately

Bead 1	Scan 2	Date of scan	17-03-2011	
		Date of reconstruction	21-03-2011	
Folder	small ring			
File	File extension	File content	File name	Size (Mb)
	HIS	Calibration of ambient radiation without object made at 3 different beam currents for a 750 ms projection time	small ring_MultGain_750ms_3p_1Det_	31.105
	HIS	Calibration of geometric of the system alignment for a 500 ms projection time	small ring_offset_500_	10.369
	HIS	Calibration of geometric of the system alignment for a 750 ms projection time	small ring_offset_750_	10.369
	IrfanView Raw file	Detector quality	DefPix_L0	20.556
	IrfanView Raw file	Detector quality	DefPix_L1	20.556
	TIFF	Detector quality	DefPix_L2	10.297
	PCA	Scan parameters	small ring	0.003
	PCP	System position during scanning	small ring	0.118
	TIFF	Raw projections	small ring0001 to small ring1441	10.279 x 1440
	TEXT document	Timing of reconstruction process	small ring bh 93	0.015
	PCR	Reconstruction parameters	small ring small ring bh 93 (bh93= beam hardening 9.3)	0.001 0.001
	VGI	Reconstituted head file	Small ring bh93	0.002
	VOL	Reconstituted volume	Small ring bh93	6554.844
	VGL	Reconstituted head file for Volume Graphics	Small ring bh93	0.013
Subfolder	[vg-project]	small ring bh93		1.06
	VGP	Visualisation files for Volume Graphics		
Subfolder	Ring small hor bh 93			6556
Files	IrfanView DCM	Reconstituted horizontal (XY) orthoslices	Ring small hor0000 to Ring small hor0999	6.556x1000