Novel volume visualisation of GPR data inspired by medical applications

Wolfgang Neubauer[1,2], Alexander Bornik[3], Mario Wallner[1], Geert Verhoeven[1]
[1]LBI ArchPro, Wien, Austria, [2]VIAS-University of Vienna, Wien, Austria, [3]LBI Clinical Forensic Imaging, Graz, Austria

Introduction

The analysis and interpretation of high-resolution GPR datasets (Trinks *et al.* 2018) is a time-consuming and complex process and requires not only three-dimensional imagination but also a broad understanding of the archaeological remains (Poscetti *et al.* 2015).

The interpretation of 3D high-resolution GPR datasets (min. 1 kvoxel/m^3) is particularly challenging, because of the amount and level of detail of the respective data. The primary task of an archaeological interpretative mapping approach is to identify archaeologically relevant structures to graphically define and classify them by adding respective attributes using a GIS environment (Neubauer *et al.* 2002). The conventional way to analyse animated stacks of 2D GPR depth-slices is similar to the way radiologists read CT or MRI datasets. However, unlike in radiology where physicians try to identify deviations from known healthy patient anatomy, the 3D nature of an archaeological site is unknown due to its unique stratification imaged in great detail by the GPR arrays.

We present a novel integrated visualisation approach inspired by medical applications, which supports conjoint visualisation of scenes composed of heterogeneous data including GPR volumes and 3D models of interpretations and reconstructions (Bornik *et al.* 2018). The approach was used in the first instance to check for the accuracy of the conventional interpretative mapping in contrast to the enhanced 3D visualisation.

High-resolution GPR datasets and data preprocessing

The high-resolution GPR datasets used for this example were recorded at the LBI ArchPro test site at the forum of the Roman town of Carnuntum (Neubauer 2014) by a motorised 400MHz MIRA from Malå Geoscience AB with a spatial resolution of 8cm x 4cm. The recorded GPR waves were band-pass filtered and migrated. The absolute amplitude of the wave was calculated in the time domain corresponding to the depth range of the 3D data cube, here set to 5cm. The resulting dataset counts 4096 voxels x 4096 voxels x 52 voxels at a resolution of 10cm x 10cm x 4cm.

Direct 3D volume visualisation shows all the details in the data, but fails to isolate meaningful large-scale structures. Contiguous visualisations of, e.g. building foundations, require a higher degree of dataset homogeneity, which can be facilitated using state-of-the-art denoising algorithms, which remove high-frequency noise while edges of large structures are preserved. Dataset filtering is performed on the GPU alongside visualisation. Filter parameters can be adjusted at any time to meet the visualisation goal (Urschler *et al.* 2014).

Data visualisation

To facilitate conventional GIS-based archaeological interpretative mapping, the GPR datasets are visualised as accumulated greyscale images for specific depth ranges (Fig. 1) or as animated sequences of the 5cm depth slices. GIS tools as developed by the LBI ArchPro are frequently used to integrate and visualise GPR datasets since they facilitate the integrated visualisation, analysis and mapping of georeferenced datasets. However, 2.5D visualisations are standard in most GIS-software and support for full 3D datasets is limited.

Software used in radiology offers direct volume rendering based on a global mapping from dataset values to colour and transparency (transfer functions), but neither offers support for non-volumetric data nor functionality for local control of the visualisation style. Other tools, like *Voxler* or *VG Studio,* are more flexible. However, their functionality to locally control the visualisation outcome and to integrate non-volumetric datasets like 3D interpretation or reconstruction models is limited.

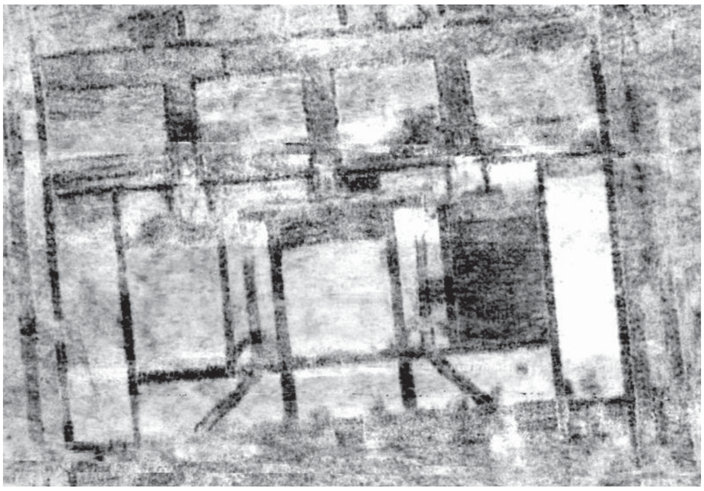

Fig. 1. Greyscale image representing the depth range between 1.0m and 2.0m of the high-resolution GPR dataset from the forum of the Roman town Carnuntum.

The proposed visualisation is based on a hybrid volume and surface data rendering algorithm (Fig. 2) inspired by developments for medical applications (Kainz *et al.* 2009). 3D models like interpretation or virtual reconstructions are rendered to a Hashing A-buffer, which provides a fast and memory efficient sorted representation of visible object entry and exit points traversed by rays from the viewpoint through each pixel on the screen (Fig. 3). These lists are traversed, maintaining a set of active objects. Colour/transparency values from the current list entry are seamlessly combined with the results from volume ray casting all active GPR objects by blending in front-to-back order. Sampling multiple filtered and unfiltered versions of the dataset using different transfer functions combined with domain control using polyhedral objects allow to visually and flexibly combine multiple features.

Fig. 2. View using the proposed visualisation techniques showing the complete GPR dataset including geometric and volumetric interpretation representations.

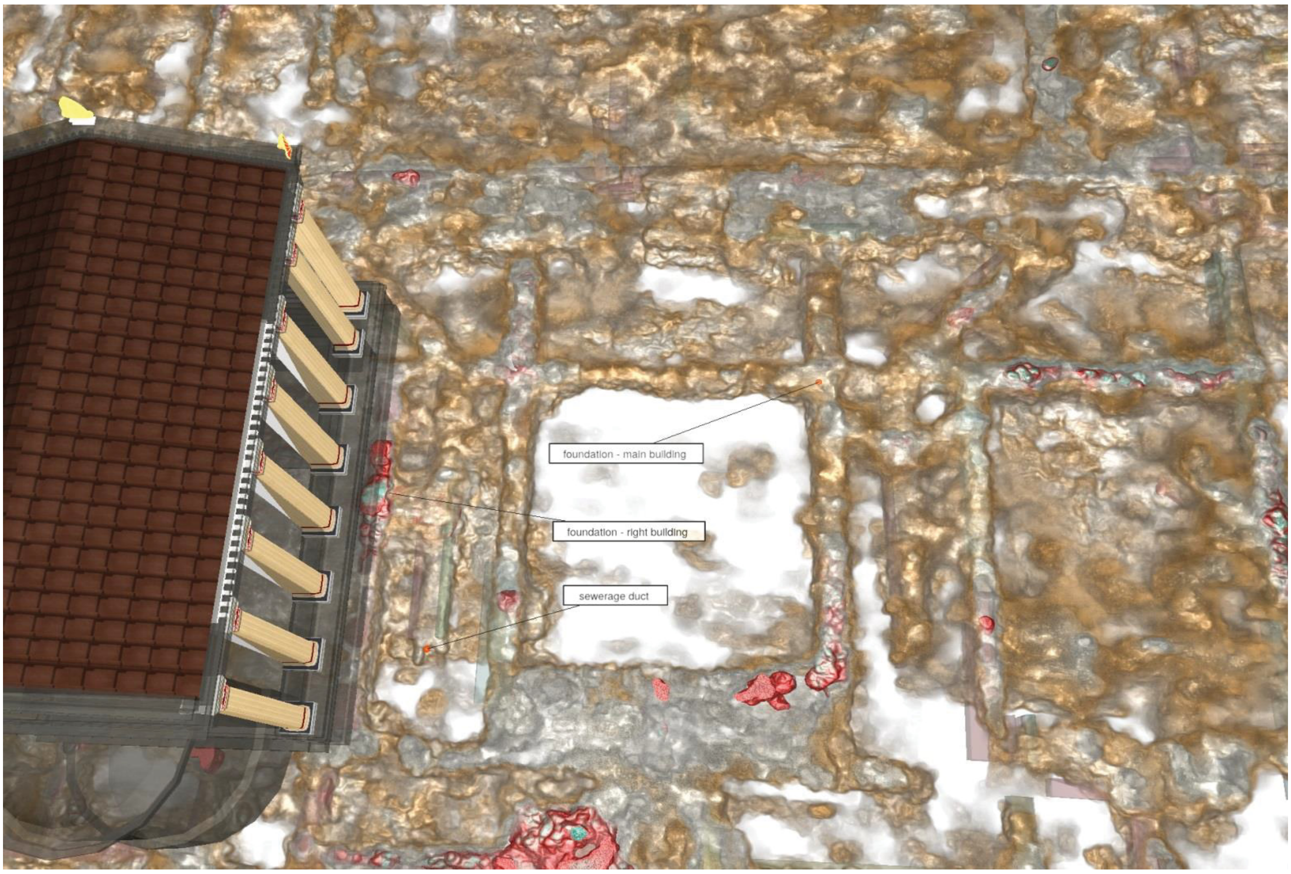

Fig. 3. Integrated visualisation of the GPR dataset, polyhedral interpretation models, a reconstructed building and textual annotations.

Conclusions and future work

The first experiments have clearly shown the potential of the proposed visualisation approach inspired by medical applications (Bornik *et al.* 2018). So far we were impressed by its fidelity over the state-of-the-art 3D visualisations applied for archaeological GPR datasets and by the possibilities to evaluate interpretations elaborated on a slice-by-slice basis comparing them to the 3D data evidence in the respective regions. Our first investigations revealed numerous interpretation inaccuracies of the results of earlier interpretative mapping approaches, which can be related to the limitations of 2D views of 3D data. Future work will, therefore, address 3D visualisation support in the data analysis and interpretative mapping phase.

Acknowledgements

The geophysical survey was conducted by the LBI ArchPro in cooperation with the ZAMG as part of the research project *ArchPro Carnuntum* funded by the Amt der Niederösterreichischen Landesregierung. The reconstructed 3D surface model was provided by Michael Klein, *7reasons*.

References

Bornik, A., Urschler, M., Schmalstieg, D., *et al.* 2018. Integrated computer-aided forensic case analysis, presentation, and documentation based on multimodal 3D data. *Forensic Science International.* 287. 12–24.

Kainz, B., Grabner, M., Bornik, A., Hauswiesner, S., Muehl, J. and Schmalstieg, D. 2009. Ray casting of multiple volumetric datasets with polyhedral boundaries on manycore GPUs. *ACM Trans, Graph.* 28(5). 152:1–152:9.

Neubauer, W., Eder-Hinterleitner, A., Seren, S. and Melichar, P. 2002. Georadar in the Roman civil town Carnuntum, Austria: an approach for archaeological interpretation of GPR data. *Archaeological Prospection*. 9(3). 135–156.

Neubauer, W. 2014. Die Entdeckung des Forums der Zivilstadt. In *Carnuntum. Wiedergeborene Stadt der Kaiser*, Humer F. (ed.). von Zabern.

Poscetti, V., Zotti, G. and Neubauer, W. 2015. Improving the GIS-based 3D mapping of archeological features in GPR data. In *Archaeological Prospection. 11th Intl. Conf.* (2015), Rzeszotarska-Nowakiewicz A., (ed.), Polish Academy of Sciences. 603–607.

Trinks, I., Hinterleitner, A., Neubauer, W., *et al.* 2018. Large-area high-resolution ground-penetrating radar measurements for archaeological prospection. *Archaeological Prospection*. 25. 171– 195.

Urschler, M., Leitinger, G. and Pock, T. 2014. Interactive 2d/3d image denoising and segmentation tool for medical applications. In *Proceedings MICCAI Workshop Interactive Medical Image Computation (IMIC)*.