Immersive Volumetric Point Cloud Manipulation for Cultural Heritage

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Abstract

In this paper, we present a framework for an immersive and interactive 3D manipulation of volumetric point clouds in virtual reality. The framework was designed to meet the needs of cultural heritage experts such as archaeologists or curators for use on cultural heritage artifacts. We propose a display infrastructure associated with a set of tools that allows users from the cultural heritage domain to interact directly with the point clouds within their study process. The resulting framework allows an immersive navigation, interaction and real time segmentation.

CCS Concepts

• Human-centered computing → Virtual reality; • Applied computing → Archaeology;

1. Introduction

Computed tomography scanning is an important source of volume data, and in a Cultural Heritage context, is used as a non destructive means of studying archaeological artefacts [JPK*06,RCD*15]. It becomes possible to assess the degradation of the artefacts, and serves as a guide in the restoration process for the implementation of a suitable protocol and the deployment of preservation means before any destructive micro-excavation operation.

For such cases, some Cultural Heritage specialists have access to two dimensional, non immersive standard tools derived from the uses in the medical field for harnessing the potential of their medical imaging data. However these tools are not designed for ease of use and oftentimes require require an amount of skill that cultural heritage specialists lack, particularly when it comes to segmentation operations.

The discrete nature of the three dimensional grid structure of DICOM (Digital imaging file format) data has oriented our research towards the use of point clouds as the main representation of the volume data. It is a representation that is supported by numerous, readily available third party softwares.

In this paper, we design and implement a framework that provides a dedicated solution to cultural heritage professionals to exploit their CT-scan data by themselves, through intuitive and easy to use real time interactive and immersive 3d visualisation and segmentation tools, we illustrate these features with three cultural heritage use cases.

2. Related works

The availability and access to ct-scans enabled the role of the CT scanner to expand into the field of cultural heritage. Indeed, this technology provides internal viewing of the material that helps to identify the internal content and to optimize the preparation of the excavation [SERPS10], [NGT*18]. But this kind of image use remains still in a limited proportion due to the difficulties of exploiting the obtained digital data.

In order to propose a volume rendering of DICOM data, the use of point cloud data has been researched and used in a variety of fields. Chougule and al [CMA13] explored three dimensional point cloud generations from ct scan images for bio-cad modeling, the resulting point cloud data was plotted on an Imageware thus presenting very basic visualisation and no interaction features.

However, an important increase of projects relying on point clouds for the encoding of data uses output from LIDAR scanning or photogrammetry techniques has pulled the development of tools to handle this kind of data in 3D environments for various application contexts such as geology [PMM*17], [KBK08], and cultural heritage [KKBM18]. These kinds of projects are only getting interested in data of surface representations and not that of volumetric data as explored here. Such projects can be found in the 2014 IEEE 3DUI contest in the theme of 3D annotation task of point-could data sets, [CMBF14], [BNB14], [VC14], [KSM*14].

Gaugne and al. [GPBG19] presented a framework for an immersive and interactive 3D manipulation of large point clouds, which was limited to surface representations and to cross-sections segmentation options.

Montano-Murillo and al [MNK*20] explored a Hybrid 3D/2D

Multi-target Selection Technique for Dense Virtual Environments, thus working on volumetric point clouds but focusing on providing a hybrid workflow combining mid-air and tablet interactions, and the advantages of the hybrid selection technique.

Maloca and al [MdCHH18] presented a Virtual Reality Volume Rendering of Original Optical Coherence Tomography Point-Cloud Data Enhanced With Real-Time Ray Casting, that allowed the user to import DICOM files into the VR program, interact with a light source and operate cross sections on the 3d representation but did not allow for segmentation of the 3d data or simultaneous manipulation of multiple DICOM files.

In summary, the previous works illustrate the interest of representing and manipulating volume data through point clouds, in virtual reality, in various domains. However, existing works are lacking in the integration of the medical imaging files as the input data, in the simultaneous and independent manipulation of point clouds from multiple sources, in the focus on Cultural heritage use and in the real time segmentation and extraction of point clouds.

3. Framework Design

3.1. Main features

Our collaboration with the archaeologists and curators involved in this project has resulted in the selection of a number of features that the user must be able to conduct, which are :
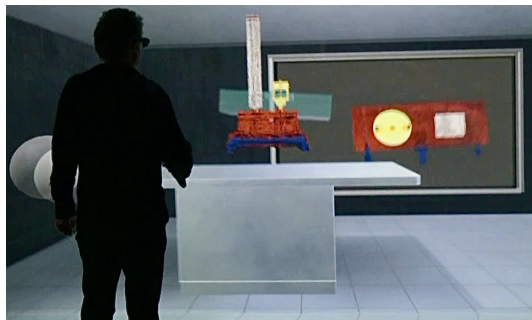

Figure 1: *Interactive cross-section: the cutting plan in blue is positioned interactively on an object and the resulting cross section is displayed on the back wall*
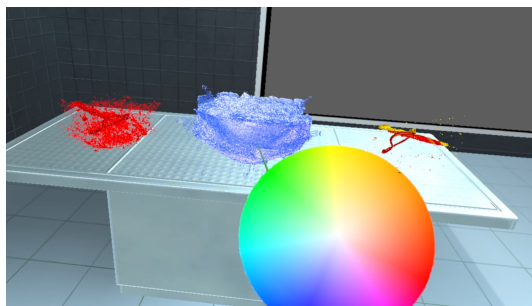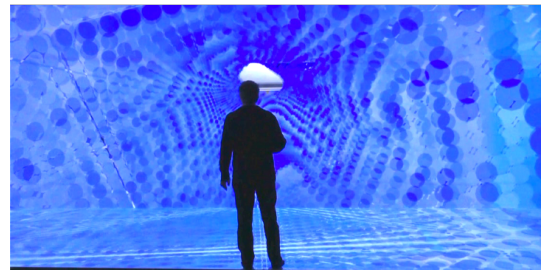

Figure 2: *Color selection.*

Figure 3: *The user navigates inside the magnified point cloud, here in the cavity of a feline long bone.*
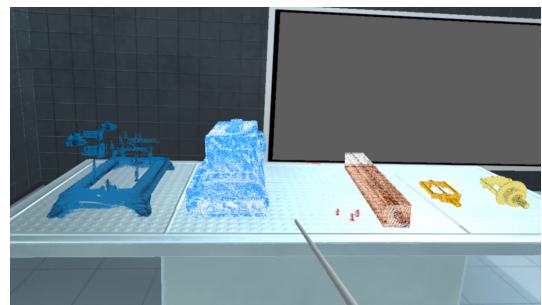

Figure 4: *Visualisation of the different point clouds of a complex machine.*

The user can view cross-sections of multiple point clouds (Figure 1), thus revealing a view on the interior in any angle or position. He can isolate the point clouds, select and extract any subset of points from the point clouds, and perform all operations on the newly generated point cloud.

The user can change the point clouds color through a handy color picker, thus modifying the perception of the point clouds (Figure 2), this feature allows to perceive surface details (topography) and identify composition of the point clouds. It can even allow to identify different wood patterns or engravings.

The user can vary the viewpoints size and investigate the 3-dimensional space, 1:1 scale for a realistic analysis, miniature for an overview and magnified to analyse morphological details, holes, empty spaces and hidden parts within the object (Figure 3).

The user can integrate and simultaneously study multiple point clouds for direct comparison [RAK19], especially in heterogeneous material such as in a complex manufactured machine, (Figure 4), or in a block excavation of an incineration (Figure 2)

The user's interactions are optimised in favor of enhanced intuitiveness and ease of use by non computer scientists. It is possible to grab and manipulate point clouds ergonomically, to handle an object in any direction, internally and at any scale, thus providing relevant support for scientific study.

3.2. Technical environment

The converter from DICOM medical imaging files to point clouds was implemented using the Python programming language, with

tkinter for the visual interface and VTK for the manipulation of the DICOM data.

As for the VR tool we use Unity version 2018.3 and rely on the point cloud importer "Pcx" (`https://github.com/keijiro/Pcx`) as a base. Tests are conducted on a VR Ready Desktop with the following characteristics : i7-9700k processor, 32GB DDR4-2400 Ram, Nvidia GTX 1080 GPU, and an Oculus Rift CV1 with touch controllers.

This tool relies on the VR plugin for Unity MiddleVR (`https://www.middlevr.com/`) as a middle-ware to manage the multiple VR visualisation hardware. It has been tested on common Hardware from Oculus Rift and HTC Vive head mounted displays, as well as the large CAVE-like facility visible in Figure 3, constituted of 4 screens, one floor of 10m x 3m, two lateral screens of 3m x 3m, and a main vertical screen of 10m x 3m, with more than 45M pixels displayed by 14 WQXGA laser projectors, driven by 7 PC, with the characteristics: 2 Intel Xeon E5-2623v4 2.6 2133 4C Processors, 32GB DDR4-2400 Ram, 2 NVIDIA Quadro P6000 24GB GPU.

4. Experimental result

We applied our framework to three different use cases, (*i*) an Iron Age cremation urn recently discovered by archaeologists [GNP*19], (*ii*) an Ancient Egyptian cat mummy from the collection of the Archaeological department of a Fine Arts Museum [GPN*18], and (*iii*) a 19th century acoustic measuring instrument from the scientific collection of a University. All these objects were scanned using the same CT scan in the context of an interdisciplinar research project in the Digital Cultural Heritage domain.

4.1. Cremation urn case

The cremation urn (Fig. 5) contains sediment, bones fragments, and three bracelets. The data was pre-segmented into three density thresholds, (*i*) the metal parts using density threshold from 3500 to 10 000, (*ii*) the bones and metal corrosion layer using density threshold from 1800 to 2500, and (*iii*) the ceramic and sediments using density threshold from 500 to 1500.

The three point clouds generated from this first step were respectively constituted of 29 550, 350 850 and 7 368 665 points. The framework allows to easily visualise and separate a block excavation containing multiple materials (ceramic, sediment, bone, and iron oxide). We were thus able to independently manipulate the point cloud of the metallic objects as shown in Figure 5-c. From this last point cloud, it was straightforward to perform the segmentation of the point cloud in the virtual reality environment to extract one of the rings as shown in Figure 5-d.

4.2. Mummy cat case

The cat mummy CT scan data also received a pre-segmentation into three density thresholds, (*i*) the bones using density threshold from 1600 to 10 000, (*ii*) the dense wrappings using density threshold from 50 to 200, and (*iii*) the outer wrappings using density threshold from -50 to 10.

The initial segmentation step allowed for the isolation of the bones, and the outer linen layers. The three point clouds generated from this first step were respectively constituted of 1 111 249, 1 451 332 and 7 567 975 points.

Focusing on the bones and making use of the scale features of the tool make possible a visualisation of the bones at different scales and allow the user to experience "walking" inside of a bone cavity (Fig. 3) and studying it at high detail.

Furthermore, the tool was used for real time extraction of specific bones for standalone analysis. The Figure 6 shows the extraction of the bone of a cat's paw from the cat's mummy, by moving the selection sphere (the white ball)

Once segmented, the generated point cloud of the bone is easy to manipulate and visualise away from the neighbouring elements and layers initially occluding it, allowing for the observation of the key elements for identification of the bone, the age, the origin ...

4.3. Cagniard siren case

The third material, the Cagniard siren, was composed of several independently scanned objects : the socle, the mechanism and two whistles. All the parts were pre-segmented into two density thresholds, (*i*) the metal using density threshold from 2000 to 20 000, and (*ii*) the wood using density threshold from -300 to 200.

The conversion step resulted in the generation of 6 different point clouds whose sizes are presented in table 1. The different point

Table 1: *Point clouds sizes.*

	metal density	wood density
Socle	1 154 391	1 476 255
Mechanism	4 725 453	NP
Small whistle	NP	724 185
Medium whistle	5 422	1 967 199

clouds generated are laid out in a 3d scene to reproduce the real setting of the siren. This use case highlights the interest of the cross section tool to visualize the assembly of the different elements before making selections and isolating the point clouds (Fig. 1). Contrasting point cloud colors also allows to easily identify the different components (Fig. 4).

We additionally used the framework's positional criteria at point cloud generation to generate a point cloud of the mechanism and a cross section point cloud revealing the internal gears.

The framework allows to visualise the composition of the studied object, to determine the nature of the components (metal, wood) and to identify the way these components were assembled during manufacture (internal screws and tubes). It is also possible to observe the usage of different types of wood and surface engravings.

5. Framework Evaluation

In order to assess our framework, we conducted a study in which we compared the model manipulation and manual segmentation features to existing software used by professionals who manipulate ct-scan data.
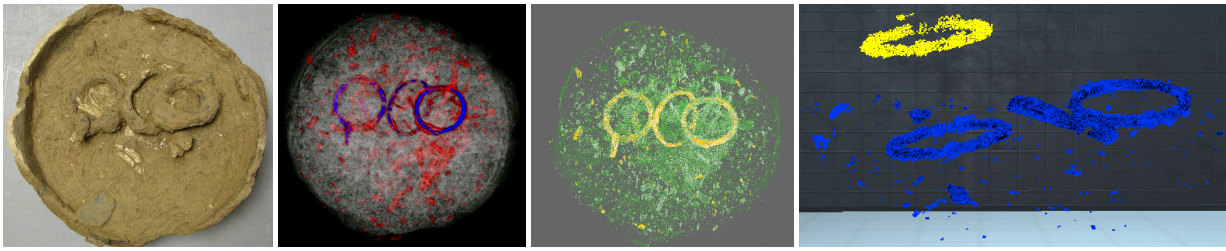
Figure 5: *Left to Right : a) Cremation Urn; b) Volume Rendering; c) Point cloud in VR; d) Segmented bracelet point cloud (yellow)*
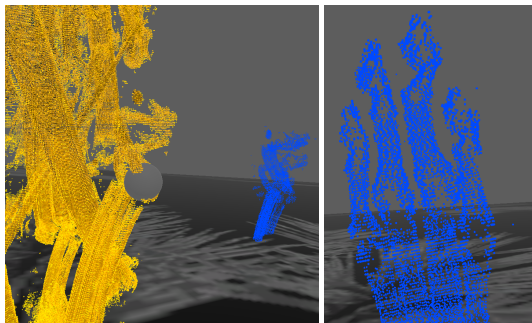

Figure 6: *From left to right : Manual segmentation of the mummy's bone point cloud and extracted paw bone point cloud*

The first software is the RadiAnt dicom file viewer. RadiAnt offers a 3d volume rendering window through which the user can manipulate the tomography scan directly in 3d and the second is the 3d point cloud processing software CloudCompare.

We organised an experimentation session at an Archaeology Institute which provided us with 7 archaeology professors who volunteered for testing with no prior experience with the tested software and tested for metrics of Task Completion Time, as well as Mean Distance and Standard Deviation between segmented models and a reference model.

By conducting One-Way ANOVA tests supported by Shapiro-Wilk Normality Tests in the three measured variables as well as Normal Q-Q plots, we determined that use of our framework provided significant enhancements to speed and accuracy of the manual segmentation in these test conditions. This encourages us to evaluate our framework further with a more important test population.

6. Discussion

The VR environment used in our framework offers a better perception of volumes during manual segmentation. The natural movement makes positioning and orientation of the user's point of view as well as the selection tool faster and more precise.

The informal discussions with the archaeologists involved in the project and the evaluations highlight the ease of use of the tools of our framework, even for uninformed computer scientists. The ergonomics of the environment facilitate its use in the context of manipulation and introspection of objects in real time. The possibility of inserting several point clouds offers the possibility of comparing several objects simultaneously. The use of different colors for the point clouds also allow to instantly identify the different components of the archaeological material under study. Among the perceived limitations, the main one is related to the nature of the point clouds which can pose a problem to characterize the empty spaces (the cavities or the interstices) of small size, or the objects whose limits are diffuse.

7. Conclusions

We presented a framework with a set of tools to manipulate volumetric point clouds in a highly immersive and interactive virtual reality environment, in a cultural heritage context. The tools were developed and used on different contexts and use cases. The framework offers an application for generation of the point clouds from the DICOM files, and an immersive VR application whose main functionalities are a segmentation tool that allows to extract any collection of points for independent manipulation, a scaling tool that allows for free roaming inside the point cloud and the ability to treat volume data from multiple sources in parallel for direct comparisons.

Further developments are underway to adapt the framework to a broader range of contexts. For example, the support of simultaneous multiple users which will enable collaboration, as it allows archaeologists to share their respective expertise and to develop relevant hypotheses as demonstrated in [FK10].

A video of presentation of the work is available here: https://youtu.be/nftIpWPsURI.

References

[BNB14] BACIM F., NABIYOUNI M., BOWMAN D. A.: Slice-n-swipe: A free-hand gesture user interface for 3d point cloud annotation. In *2014 IEEE Symp. on 3DUI* (2014). 1

[CMA13] CHOUGULE V., MULAY A., AHUJA B.: Three dimensional point cloud generations from ct scan images for bio-cad modeling. 1

[CMBF14] CABRAL M., MONTES A., BELLOC O., FERRAZ ET AL. R.: Bi-manual gesture interaction for 3d cloud point selection and annotation using cots. In *IEEE Symp. on 3DUI* (2014), pp. 187–188. 1

[FK10] FORTE M., KURILLO G.: Cyberarchaeology: Experimenting with teleimmersive archaeology. In *16th Int. Conf. on Virtual Systems and Multimedia* (2010), pp. 155–162. `doi:10.1109/VSMM.2010.5665989`. 4

[GNP*19] GAUGNE R., NICOLAS T., PETIT Q., OTSUKI M., GOURANTON V.: Evaluation of a Mixed Reality based Method for Archaeological Excavation Support. In *ICAT-EGVE 2019 - International Conference on Artificial Reality and Telexistence - Eurographics Symposium on Virtual Environments* (Tokyo, Japan, Sept. 2019), pp. 1–8. URL: `https://hal.inria.fr/hal-02272910`. 3

[GPBG19] GAUGNE R., PETIT Q., BARREAU J.-B., GOURANTON V.: Interactive and Immersive Tools for Point Clouds in Archaeology. In *Int. Conf. on Artificial Reality and Telexistence and Eurographics Symp. on Virtual Environments* (2019). `doi:10.2312/egve.20191283`. 1

[GPN*18] GAUGNE R., PORCIER S., NICOLAS T., COULON F., HAYS O., GOURANTON V.: A digital introspection of a mummy cat. In *2018 3rd Digital Heritage International Congress (DigitalHERITAGE) held jointly with 2018 24th International Conference on Virtual Systems Multimedia (VSMM 2018)* (2018), pp. 1–8. 3

[JPK*06] JANSEN R. J., POULUS M., KOTTMAN J., DE GROOT T., HUISMAN D. J., STOKER J.: Ct: a new nondestructive method for visualizing and characterizing ancient roman glass fragments in situ in blocks of soil. *Radiographics 26*, 6 (2006). 1

[KBK08] KREYLOS O., BAWDEN G. W., KELLOGG L. H.: Immersive visualization and analysis of lidar data. In *Advances in Visual Computing* (2008), Bebis G., Boyle R., Parvin B., al., (Eds.), Springer Berlin Heidelberg, pp. 846–855. 1

[KKBM18] KULIK A., KUNERT A., BECK S., MATTHES ET AL. C.-F.: Virtual valcamonica: Collaborative exploration of prehistoric petroglyphs and their surrounding environment in multi-user virtual reality. *Presence: Teleoperators and Virtual Environments 26* (2018). 1

[KSM*14] KRAMMES H., SILVA M. M., MOTA T., TURA M. T., MACIEL A., NEDEL L. P.: The point walker multi-label approach. In *IEEE Symp. on 3DUI* (2014), pp. 189–190. 1

[MdCHH18] MALOCA P., DE CARVALHO E., HEEREN T., HASLER ET AL. P.: High-performance virtual reality volume rendering of original optical coherence tomography point-cloud data enhanced with real-time ray casting. *Translational Vision Science & Technology 7* (07 2018). `doi:10.1167/tvst.7.4.2`. 2

[MNK*20] MONTANO-MURILLO R. A., NGUYEN C., KAZI R. H., SUBRAMANIAN S., DIVERDI S., MARTINEZ-PLASENCIA D.: Slicing-volume: Hybrid 3d/2d multi-target selection technique for dense virtual environments. In *IEEE Conference on Virtual Reality and 3D User Interfaces* (2020), pp. 53–62. 1

[NGT*18] NICOLAS T., GAUGNE R., TAVERNIER C., MILLET E., BERNADET R., GOURANTON V.: Lift the veil of the block samples from the Warcq chariot burial with 3D digital technologies. In *Digital Heritage, IEEE* (San Francisco, United States, 2018), pp. 1–8. 1

[PMM*17] PALHA A., MURTIYOSO A., MICHELIN J.-C., ALBY E., GRUSSENMEYER P.: Open source first person view 3d point cloud visualizer for large data sets. In *The Rise of Big Spatial Data* (Cham, 2017), Springer International Publishing. 1

[RAK19] RENCHIN-OCHIR A., ALTANTSETSEG E., KONNO K.: A study of analyzing shape similarities between the arm model of mongolian buddha statues for archaeological applications. In *2019 Int. Conf. on*

Cyberworlds (CW) (2019), pp. 387–390. `doi:10.1109/CW.2019.00074`. 2

[RCD*15] RE A., CORSI J., DEMMELBAUER M., MARTINI M., MILA G., RICCI C.: X-ray tomography of a soil block: A useful tool for the restoration of archaeological finds. *Heritage Science 3*, 4 (01 2015). 1

[SERPS10] STELZNER J., EBINGER-RIST N., PEEK C., SCHILLINGER B.: The application of 3d computed tomography with x-rays and neutrons to visualize archaeological objects in blocks of soil. *Studies in Conservation 55* (06 2010), 95–106. 1

[VC14] VEIT M., CAPOBIANCO A.: Go'then'tag: A 3-d point cloud annotation technique. In *2014 IEEE Symposium on 3D User Interfaces (3DUI)* (2014), pp. 193–194. 1