Computed Tomography as a Tool for the Examination and Archiving of Musical Instruments

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ABSTRACT: 3D Computed tomography (3D CT) is an established method for the non-destructive examination of objects of cultural heritage. Especially industrial facilities which are mainly used for material testing can provide high resolutions and excellent image quality. This allows a lot of applications for the deep study of many objects like musical instruments. Using the generated "digital twin", the inner structure and the construction of an object can be explored. This includes damages, repairs and later alterations. The high resolution provides information about tool marks and the different densities of material, so the whole process of production and usage can be reconstructed. Post-processing the data can extend the range of information and applications for example in the field of restoration and conservation or sound research. On the basis of the tomography data, 3D surfaces models can be generated and used for example for the reproduction of missing parts through 3D-printing or CNC-milling. Furthermore, the data can be used for documentation in the field of the digital humanities and visualization in the context of transferring knowledge as well as for archiving objects in case of repatriation.

1. INTRODUCTION

3D computed tomography (CT) is an imaging method which is widely used for medical purposes and industrial non-destructive testing. For the examination of objects in museums and other institutions it can be used for manifold applications. The object can be examined by cross sections in every direction, with surface renderings of all parts or by taking measurements at every (otherwise inaccessible) location. A CT data set represents a "digital twin" of an object that has a lot of similar features and can be studied without actually touching the object. This can be helpful in case of sensitive materials or fragile conservational state. The digital twin can also be displayed and explored by visitors or researches without the restrictions of a physical object. For collections which hold objects with uncertain provenance this technique can be used for archiving the particular object and keep it as digital representation in case of repatriation. This can concern for example ethnological collections which obejcts were collected during the time of colonialism under uncertain circumstances. In some cases these collections hold also objects of ethically sensitive materials like human remains. Since a digital twin does not underlie the same ethical criteria for examination and exhibition of such objects a 3D CT scan can serve as a substitute e.g. in ethnological exhibitions.

2. DIGITIZATION USING 3D CT

During an X-ray CT scan numerous single images are recorded from different angles of an object. All single images are later computed to a 3D data set which is a digital representation of the object with all structural information about the inner and outer surface (apart from the colour) and internal parts. In a medical scanner the patient or the object lies on a cot and an X-ray tube and detector are rotating around them hidden in a white tube. The CT facilities for industrial applications are different. Here, the object is placed on a rotation table between X-ray source and detector. Unlike in the medical scanner, this setting is not optimized for human bodies but can be adjusted to the needs of different objects. Thus, higher energies can be used for the irradiation of objects with higher densities and better resolutions can be achieved. While the medical scanner is more or less fixed on a spatial resolution around 400 µm, industrial scanners can produce a higher quality where details in musical instruments from around 50 µm to 100 µm can be distinguished.

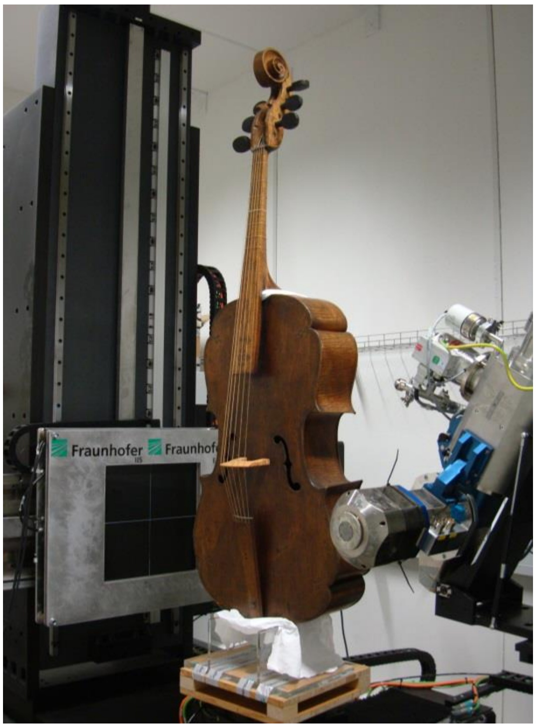

Figure 1: *A bass viol by Hanns Vogel (Germanisches Nationalmuseum, Inv. Nr. MI 5) on a CT-facility of the Fraunhofer EZRT, Fürth.*

During the DFG-funded MUSICES-project (**MUS**ical **I**nstrument **C**omputed tomography **E**xamination **S**tandard) from 2014-2018 the Germanisches Nationalmuseum, Nuremberg scanned in collaboration with the Fraunhofer EZRT in Fürth more than 100 different musical instruments using different industrial and medical scanning methods in order to develop recommendations for the executions of such scans [1]. Recommendations will be published by the end of 2018 on the webpage of the project www.musices.gnm.de.

2. QUALITY OF A DIGITAL TWIN

For being a suitable "digital twin" the scan has to provide a certain image quality. Mostly this is identified as spatial resolution but also the signal-noise ratio is from major importance for a digital examination of an object.

For the examination of many scientific issues on musical instruments, a resolution of 100 µm or better is required. This resolution can be achieved with industrial X-ray computed tomography. With this image quality, measurements can be made on all locations with high precision, sections of, for example, a top plate of a violin can be used for dendrochronological analysis and details like repairs and tool-marks can be distinguished. Also a surface model can be generated with high accordance to the original. This can be used for reproduction using additive methods like 3D printing or using milling technique (CNC).

2.1 MOUNTING AND MATERIAL

X-rays are attenuated by material. Therefore, material density and thickness play an important role for the selection of the setup. Wooden objects can be transmitted by lower X-ray energies than for example brass instruments. For the examination of wooden instruments the best image quality can be achieved with lower energies around 150 kV up to 225 kV. For the examination of very dense materials like brass instruments or sections of instruments with a high amount of metal parts high energies up to 600 kV can be used. Since musical instruments often consist of materials with highly differing densities, the choice of the appropriate energy is a challenge. Metal parts like a nail in the neck of a violin can cause strong image errors, called artifacts. Mostly these metal parts cannot be removed due to conservational reasons. To avoid these artifacts, a filtered spectrum can be used and instruments have to be positioned in the beam in a way that avoids long transmitted distances. A slightly angled position can help to reduce artifacts for example when there are metal rings, frets in a fingerboard or pegs. Another approach of the project was to combine measurements with two different spectra. This method can enhance the image quality of sections with metal parts like the key of a clarinet [2].

When positioning the object, there are two things to consider. First, the object should be placed as stable as possible. A carbon fiber tube fastened on a wooden plate can be a simple and stable construction. To this tube objects with different geometries can be fastened. The stability is an important issue. If the object moves, the images will represent two objects at different positions and double structures will be the result. Second, the mounting should be as small as possible. Every added material will increase the volume to be scanned and thus decrease the best possible magnification i.e. resolution and also attenuate the X-rays.

2.2 SIZE OF OBJECTS

In industrial CT-devices the object is fixed on a rotation table between source and detector. Today, the most common type of detector is a flat panel and with a size of 40 cm x 40 cm. Objects smaller than this can be fully depicted on this plane. For bigger objects or in order to have a larger magnification, the detector can be moved upwards and sidewards. Since computed tomography generates volume data, it is easy to imagine that, for a given resolution, the scan of a big instrument will produce a big amount of data. One rotation on the turntable will produce 1200 to 2400 single images. If the detector has to be moved once, the amount of images but also of scanning time and X-ray-dose is doubled. The single images (raw data) will be transformed by special algorithms to the 3D-data set, which are called reconstructions. For a small instrument, like a violin or a recorder, the detector can be moved during the rotation of the turntable (helical process). For broader instruments the extension of the field of view has to be done also horizontally.

If there is only a specific issue on just one part, only this section (volume of interest) can be scanned, mostly faster and in a higher resolution compared to a scan of the entire object. There are several regions of a special interest in musical instruments such as the area around a tone hole of wind instruments, connecting parts (corner joints, upper block, tenon etc.) or details on the surface, traces of tools, damages or parts carrying additional information like the annual rings of wood which can be used for dendrochronological dating. It is not always necessary that the entire instrument is fully depicted on the detector during the whole rotation. Using e.g. the so called Hilbert-reconstruction, it is also possible to depict truncated parts [3].

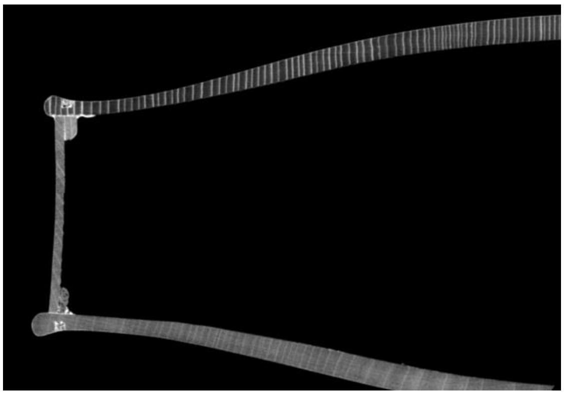

Figure 2: *A region of interest of a violin (Germanisches Nationalmuseum, Inv. Nr. MI 419) with a high spatial resolution*

2.3 DOCUMENTATION & ARCHIVING

To ensure long term use and further examination for scientific purposes, a persistent data management system is critical. In the case of 3D CT of musical instruments, the MUSICES project developed a meta data model and database that can be used for analysis of the objects scanned during the project and will also be available for future projects and research. In this database, all relevant information on the object and the technical parameters of the scan are documented in detail.

A typical CT scan campaign can be grouped into three areas: the object description, the actual scan and the reconstruction and evaluation. Creating an object description prepares the CT scan and provides the required information for the scan. Size and material of the object as well as the way how it can be mounted on the rotation table determine the technical parameters and influence image quality. For the scan itself the technical setup (X-ray source and detector) and all parameters like tube voltage, current, measurement method, amount of single images etc. have to be recorded. In the third step of a CT examination process, the single image is converted to a 3D data set using specific algorithms, which is called reconstruction. The images can only be understood and replicable if this work step is also documented. At the end, the volume of images can be viewed and results can be evaluated.

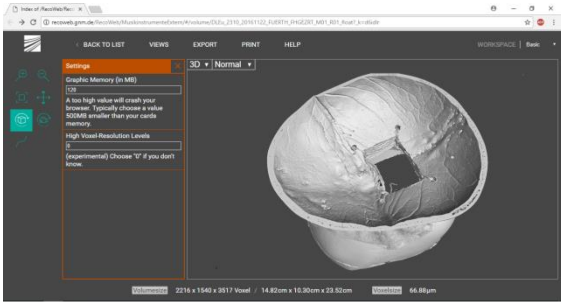

Figure 3: *A Tibetan skull drum (damaru) displayed in the RecoWeb-viewer how it is used in the MUSICES database*

In the MUSICES database all this information is correlated using a persistent identifier which consists of several elements like the Sigel of the collection (DLEu for the Leipzig collection according to the ICOM CIMCIM Sigel list), the inventory number, the date, the place and the institution of the scan, the chronological number of the scan and the chronological number of the reconstruction. In the case of the object in Fig. 3, the identifier and the name for a data is :
DLEu_2310_20161122_FUERTH_FHGEZRT_M01_R01

The entire database is built using the CIDOC-CRM ontology (ISO 21127:2006), a reference model which provides definitions and a formal structure for describing the implicit and explicit concepts and relationships used in cultural heritage documentation. The database is more than a simple data storage system. The so called WissKI (German abbreviation for scientific communication infrastructure) organizes and connects the data sets according to the ontologically defined entering fields and allows a targeted workflow and organization of the different entries. All meta data is correlated to the actual volume data set in a bijective way.

The storage format has to be chosen carefully. Many providers of industrial CT scanner use proprietary formats and it can be questioned whether these formats will remain readable in the future. The format DICOM (Digital Imaging and Communications in Medicine) is used for many medical imaging techniques and presents a good choice for long term archiving. Given the law in many countries require the storage of medical imaging data for many years; the DICOM format has potential longevity.

2.4 DISPLAY

One challenge for a database of CT scans is the online display of big data sets. Due to the high resolution of the scans, the volume data sets of objects are rather large. The data set of an entire vilolin can have a size of up to 60 GB. Usually these volume data sets can only be processed using hardware with high computational power and specialized software. For the MUSICES website a web viewer is used which can display big data sets via internet. The entire 3D data set can be opened and analysed using only a common internet browser [4]. The database provides open access to research data without any required specialised hardware or software. This is possible due to a pre-processing step of the software which fragments the volume in small portions which are easier to display. The MUSICES-database can be used as an exemplar for the combination of a persistent meta data archiving structure and the presentation of the actual volume data set. It hosts meta data and displays ca. 230 data sets of more than 100 musical instruments. This information can be connected to more specific databases, for example, on intangible cultural heritage. In conjunction with recordings or videos, the CT images of musical instruments could give a good representation of a musical practice and serve as a tool for archiving. As a consequence, open access to a rather large amount of data is provided to a huge community of researchers.

3. CONCLUSION

Museums have the responsibility to preserve, disseminate and impart cultural knowledge as well as provide items for research. In the case of human remains or objects which were acquired under doubtful circumstances, museums try to find suitable ways to satisfy ethical needs. 3D digitization methods like X-ray CT can influence traditional museum research, archival and communication methods. They can change the availability and access of objects and affect the way knowledge is created. They could provide a new, modern and progressive approach for handling repatriation and the treatment of sensitive objects.

The digital representation of an object has to be seen as something innovative. The 3D model is an artifact by itself and a product of a cultural progress. It has its own value and has different properties than the original. Thus, it is more than just a copy. It can forge new interactions with the original and a new relationship to museum objects. The UNESCO Charter on Digital Heritage published in 2002 claims an equally professional preservation for cultural heritage data as well as for physical objects and demands open accessibility to the generated data. By using open formats and as well as through the integration of international databases like MIMO, Europeana and MUSICES, the objects can be connected in diverse research contexts or educational concepts. The digital model of the object can be preserved, explored and distributed even if the original object is repatriated

4. ACKNOLEGMENT

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5. LITERATURE

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