Opening Black Boxes: 3D-CT digitalisation of historical cipher machines

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1. INTRODUCTION

Within the framework of the three-year project “3D-Cipher” – funded by the German Federal Ministry of Education and Research – the Deutsches Museum is conducting computed tomographic scans of 60 historical cipher machines of its collection. The museum is thereby extending its experience with CT scans as part of the large-scale digitisation measures established in the previous years. First projects utilising computed tomographic scans have been carried out in the past, like the large-scale scan of the WWII aircraft Messerschmitt Me 163 (www.iis.fraunhofer.de/en/profil/jb/2019/xxl-ct-me-163.html). The non-destructive look inside historical objects is the primary advantage for the use of the CT technology in the Deutsches Museum. Many exhibits cannot be opened physically for conservational concerns, e.g. many of the crypto devices. The CT technology thus gives us insights into historical objects, which would not be possible otherwise without destroying the fragile devices.

2. TECHNOLOGY

The CT technology uses X-ray measurements from various angles for the capturing. While technologically similar to medical CT scanners, industrial CT scanners move the object instead of the scanner itself and the X-ray beam uses higher electromagnetic radiation, which is necessary to penetrate dense materials like metal.

The resolution of industrial CT scanners depends on the size of the facility and the scanned object. Nano-CT scanners reach resolutions up to 0.5 μm, while the Macro and XXL scanners of the Fraunhofer EZTR (https://www.iis.fraunhofer.de/en/ff/zfp.html) used in the 3D-Cipher project can create resolutions up to 0.15 mm.

Different materials absorb the x-ray beams to different degrees. As a consequence, denser materials appear lighter in the final images than materials with lower density. This is usually represented in a grey scale histogram. The result of the scanning process are thousands of individual x-ray images from which one can reconstruct a digital 3D-CT model.

3. BENEFITS AND EXPLOITATION

The CT technology adds value in different ways to the museum work. The before mentioned non-destructive view inside historical exhibits generates new knowledge about the specific object history. The operating mode of cipher devices from the 1970s onward is barely known and they cannot be opened without potentially destroying parts of the mechanism. Even for well-researched machines like the Enigma, the CT scans can add value with the possibility to measure in the submillimetre range. The results can be used to improve and build functional replicas.

Figure 1: Rotor of an Enigma M4, colourized 3D-CT model.

The technology can also answer conservational questions with different material analysis tools. Via
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structural mechanical analysis, it is possible to identify damaged or destroyed parts or material degradation, e.g. the strong corrosion of the outer and inner parts of our cipher device SG 41 is visible in the CT images.

Apart from research questions, 3D-CT data can complement museum exhibitions and help explain complex issues. Since we can identify, extract and animate individual parts, the CT technology contains a lot of potential for museum communication.

Figure 2: Segmented and colourized parts of the cipher device Kryha Standard, 3D-CT model.

4. CHALLENGES

Nevertheless, it is also important to mention the limitations and challenges of the computed tomography technology. The biggest issue with large scale CT scans is their high costs, easily ranging in the tens of thousands of euros. Consequently, large-scale CT digitisation is almost impossible to achieve for publicly funded museums. Additionally, the analysis and visualisation software by the market leaders is very expensive. There are however very powerful open source alternatives like 3D slicer (https://www.slicer.org/).

It also takes time to learn how to read the data and pictures, e.g. to distinguish between digital artefacts and deviations in the real object. This is especially true for largely mono-material objects. A surface determination, often required for further analysis, is much more accurate if it can be based on clearly distinguishable grey scales. The segmentation of different parts, like the mechanism of a machine, is therefore a difficult and time-consuming task.

Furthermore, the created CT data is very large. Depending on object size and resolution, the files reach up to 50 GB or even 500 GB. This requires expensive hardware and variable downsizing for online viewers. Two promising web viewers are the RecoWeb viewer of the Fraunhofer EZRT (https://recoweb.gnm.de/extern/Musikinstrumente) and the open source viewer MorphoSource (https://www.morphosource.org).

Figure 3: Colourized 3D-CT model of the “Schlüsselgerät SG 41”, intended to be the successor of the famous Enigma in WWII.

Other challenges are the long-term data storages and the required servers to host the data. The Deutsches Museum is involved in different (research) data infrastructure projects and initiatives to challenge these issues for all kind of research data (https://4memory.de/; https://www.kultsam.de).

The self-imposed expectations of the 3D-Cipher project align with the abovementioned benefits and challenges, to prepare and supply open source data for research and to use this data to display them to the public and the museum visitors. In addition, we reflect the working process, the challenges for researchers and the possibilities of creating a sustainable digital infrastructure.

5. REFERENCES

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