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Comparison of different experimental approaches in the tomographic analysis of ancient violins

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ABSTRACT

X-ray computed tomography (CT) is now a common technique for the non-destructive structural analysis of ancient manufacts of cultural and historical relevance, providing luthiers, art historians, conservators and restorators with a unique tool for the characterization of musical instruments. The experimental set-up to choose is obviously related to the kind and accuracy of the information to be extracted. Some applications of the technique require to examine extremely small details in selected parts of a violin, as in the evaluation of small cracks and thin patches, or in the characterization of larvae and eggs of wood-destroying insects. Other approaches, on the other hand, require less precise measurements of the size of the violin and its main components. Sometimes the presence of metal parts, such as strings and keys, requires a high dynamic range X-ray detector. Other parameters to be taken into account are related to the general organization of the experiment, such as the time required for the measurement, the distance of the laboratory from the instrument owner, its availability and, of course, the cost of the service.

1. Introduction

Computed tomography (CT) is a well known technique for the morphological characterization of bowed stringed instruments, and has been extensively used by luthiers and acoustic scientists for almost twenty years. Since the first pioneering studies in 1992 and 1993 [1,2] on a clinical CT system, other authors have described the application of the same technique to historical instruments [3–5], confirming the potentiality of the approach. The information derived by CT analysis have an important role in the valuation, insurance, and identification of valuable stringed instruments such as violins, violas and cellos. Moreover, it is well known that many serious damages may be concealed with glue, filler material, retouch, or varnish. Other abnormal conditions that affect the performance and the value of these instruments include damages caused by the infestation of larvae. Additionally, CT analysis allowed identification of the internal wood grain pattern unique to each instrument, facilitating verification of authenticity and protection against loss, theft or forgery. Data extraction is straightforward and can be treated digitally in several ways. A similar study, on wind instruments, has been performed by K. Martius and M. Raquet [6].

The study described has been dedicated to a deeper understanding, from a qualitative point of view, of advantages and limitations of different approaches in the morphological study of a violin: a conventional clinical CT, a commercial micro-CT system and a micro-CT synchrotron beamline.

The data acquisitions were performed in three different laboratories, with three radically different tomographic systems: a Toshiba Aquilion 16 clinical tomographic system at the Ospedale Maggiore of the Trieste Ospedali Riuniti, Italy; a GE Phoenix v|tome|x L 240 micro-CT station at the Faculty of Mechanical Engineering, Brno University of Technology, Czech Republic; the SYRMEP micro-CT synchrotron radiation beamline at Elettra-Sincrotrone Trieste, Italy.

The measurements were performed on the same violin in order to compare the results. The instrument was an old (∼1850) Austrian violin with several cracks, damages and woodworm attacks. The body was 357 mm long and 208 mm wide. The final results were compared on the basis of several considerations: the main concern was obviously related to the quality of the final reconstructed images, taking into account the spatial resolution and the dynamic range of the final images, as well as the presence and relevance of reconstruction artefacts. Other parameters we considered,

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in order to compare the different approaches also from the point of view of the working conditions were related to the time necessary for the acquisition and reconstruction, to the amount of scans performed in a typical measurement, to the amount of data generated, the computing system necessary to manage them, and to the availability and cost of the access to the different facilities.

2. Experimental setups

2.1. The clinical tomographic system

The tomographic images on a clinical instrument were taken at the Ospedale Maggiore of the Trieste Ospedali Riuniti. The radiology department uses a Toshiba Aquilion 16, a third generation multi-slice helical CT scanner featuring a 60-kW generator, 7.5 MHU tube and a standard gantry rotation time of 0.5 seconds. In helical mode it is capable of acquiring multiple parallel rows of data per rotation, with collimations of 16 × 0.5 mm, 16 × 1 and 16 × 2 mm. The best images, in terms of resolution and contrast, were achieved with a 120-kV peak voltage and a 200-mA current. The active area of the detector is characterized by 512 × 512 pixels for an isotropic voxel size of 0.46 mm. In this configuration the total acquisition time for the violin body (i.e. without the neck) was about 1 minute, while the reconstruction took less than 4 minutes. The total data set size was 150 MB in DICOM format (easily convertible to TIFF format for viewing with any software). The Toshiba detector software supports FDK approximate reconstruction. Due to the negligible spatial coherence of the source, no phase contrast effects were present in the final images.

2.2. The micro-CT station

The analysis on a micro-CT station has been performed at the Faculty of Mechanical Engineering, Brno University of Technology, Czech Republic. The laboratory uses a GE Phoenix v|tome|x L 240 micro-CT station, a high-resolution 320/450 kV microfocus system for 3D computed tomography and 2D non-destructive X-ray inspection of e.g. large castings, welding seams and electronic devices. It works in cone-beam configuration using circular trajectory and can accomodate several types of detectors. In our study we chose to use the GE DXR250, a 14/16 bit high-contrast digital detector array (DDA) with 200 μm pixel size, approx. 400 × 400 mm sensitive surface, 2024 × 2024 pixel. The system supports virtual detector enlargement for large samples. The analysis has been performed with a 60 kV peak voltage and a 1000 mA current. The tomography of the whole violin body has been made in virtual detector enlargement, i.e. (2024 × 2) × 2024 for an isotropic voxel size of 0.080 mm. Taking into account 2400 projections for scan, the total acquisition time on the six scans necessary to image the whole violin was about 8 hours for a total data set of 220 GB of acquired projections and 77 GB of reconstructed slices in TIFF format. The GE proprietary detector software supports FDK approximate reconstruction.

2.3. The synchrotron micro-CT beamline

The experiment was carried out at the SYRMEP beamline [7] of the Elettra Laboratory in Trieste, Italy. The violin was positioned at 29 m from the bending magnet source, where the beam dimensions are 220 (H) × 3.5 (V) mm. The detector of choice was a Teledyne DALSA Argus DQ, a 16 bit, high dynamic range CMOS with a scintillator optimized for mammographic applications. The active area of the detector is 221 × 6.9 mm with a pixel size of 27 μm. The tomography of single slices was taken with 2400 projections for a total time of 2.3 hours. The reconstruction took only few minutes and the data set of a slice was about 10 GB in TIFF format. The data have been analysed following the procedure and the software described in ref. [8].

3. Experimental results

3.1. The clinical tomographic system

Clinical CT has proven to be an extremely valuable tool in the morphological analysis of musical instruments in general, and of bowed stringed instruments in particular, where its main advantage is related to a complete non-intrusive, non-invasive approach. Data extraction is straightforward and can be treated digitally in several ways. The access to this kind of instruments is rather easy, and an entire instrument can be scanned in few minutes. On the other side they are "closed" instruments, and working parameters cannot be chosen with complete freedom. The main limitation, however, is related to the low spatial resolution of commercial instruments, where the state-of-the-art voxel size is of the order of 0.2 × 0.2 × 0.2 mm^3. Every defect with lateral dimensions smaller than this value cannot, therefore, be detected with state-of-the-art hospital instruments. Fig. 1 shows a rendering of the whole instrument, while Fig. 2 shows some major details of the internal structures, such as larger wormholes in different part of the violin body. Important details such as smaller cracks or the presence of repairs cannot be detected.

3.2. The micro-CT station

The last few years have seen an incredible progress in the performance of CT stations, and the market offers a wide choice of instruments with an extreme variety in terms of X-ray energy range, spatial resolution and dimensions, which can go from the tabletop configuration to a very large hutch. The conical beam configuration, in particular, allows to examine samples of important dimensions, such as a whole violin, and to select the desired spatial resolution. Very often these stations can also accommodate different detectors in order to increase their flexibility. Spatial

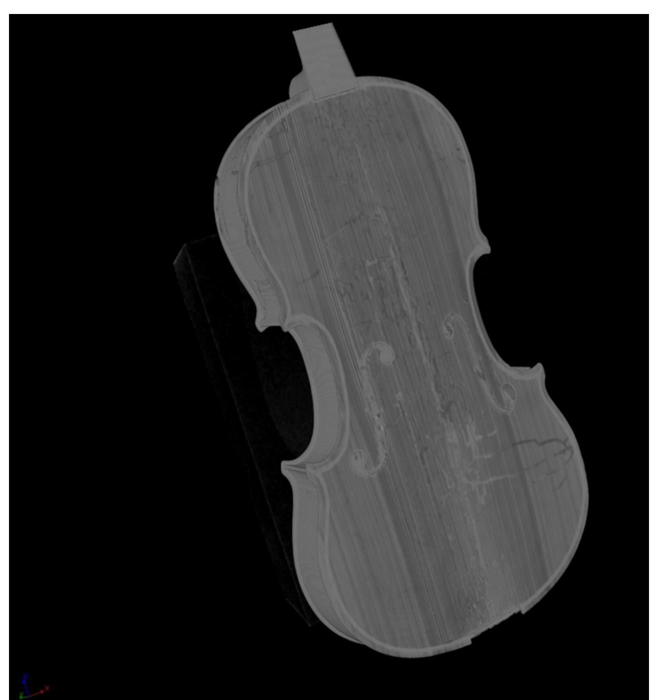

Fig. 1. 3D rendering of the violin at a clinical CT.