Analysis of Baroque Sculpture Fusing Data of X-Ray Fluorescence Imaging with X-ray Computed Tomography

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Abstract
It is advantageous to combine information about geometry and the inner structure of historical artifacts with information about the elemental composition of decorative layers, typically covering historical wooden sculptures. X-ray computed tomography describing artifact structure is quite common and easy. Standard X-ray fluorescence (XRF) analysis of decorative layers is typically done for several selected spots of the artifact’s surface utilizing single pad detector. XRF imaging fully describing the surface’s elemental composition is commonly done for flat objects, while time consuming XRF tomography is applied to relatively small objects. It will be shown in this work that an effective fusion combination of XRF imaging and X-ray tomography describing the whole object can be realized even when using a limited number of XRF images.

Keywords: X-ray Computed Tomography, X-ray Fluorescence Imaging, Cultural Heritage, Data fusion

1 Summary
It is well known that non-destructive three dimensional inspection of the Cultural heritage object is advantageous from many reasons – documentation, preparation for restoration, dating, investigation of the manufacturing technology [1] etc. On other hand, many artefacts are covered by thin decorative layer for which evaluation of the element composition is important especially if such layer is hardly deteriorated during years [2].

To reveal the internal geometry of an object in high-resolution, X-ray computed tomography (XCT) is the ideal tool by quantifying the microstructure in three dimensions. Resolution of the XCT is limited by the detector pixel size and by the object dimension (it is limiting factor for possible magnification). Therefore XCT description of the object surface layer is not sufficient in many cases. X-ray Fluorescence (XRF) imaging [3] can be taken as complementary technique to the XCT. It will be shown, that mapping of the XRF data onto the surface of tomographically reconstructed object is advantageous as relations between object geometry and material composition of its surface can be identified by this way. Such data fusion will be demonstrated on a baroque carved wooden polychromed and silvered Pieta sculpture, which is richly decorated. See Fig. 1 for its photography. This Pieta was made in the 17th century in Bohemia.

The Twinned Orthogonal Adjustable Tomograph (TORATOM) [4], utilized for XCT and XRF measurement has the capability to meet variable requirements regarding different radiographic and tomographic measurements, for instance the 2D scanning of relatively large samples as well as standard, dual-source [5] or dual-energy tomography [6] in different magnifications. TORATOM consists of two independent X-ray imaging lines in an orthogonal arrangement, with a shared rotational stage (Aerotech). TORATOM is equipped with 160 kV nanofocus and 240 kV microfocus tubes (X-RAY WowX GmbH). Detector holders allow the quick and easy replacement of the desired type of detector, Perkin Elmer flat panel with a 400 x 400 mm area and 200 μm pixel pitch was used for CT measurement. The gamma/XRF camera (XRF camera hereafter) used in this work has 100 μm pinhole and it is equipped with two stacked Timepix detectors. The pixelated Timepix detector [7] controlled by Pixelman software [8] can be operated in time-over-threshold mode (ToT), which enables measuring the energy of each incident photon [9], utilizing single event analysis [10]. One of the possible applications of this detector is XRF imaging [3].

Fusion of the XRF data and tomographic reconstruction is done as follows. The reconstructed volume (3D matrix) is binarized, i.e. a value of 1 is written into voxels which have a value higher than the given threshold (corresponding to air) and a value of 0 is written into voxels with a value lower than the same threshold. The coordination system of the volume is rotated to have vertical slices parallel with the XRF camera detector. The XRF image is multiplied with vertical slices in successive steps from the slice nearest to the XRF camera up to the furthest slice. When the first voxel with a value of 1 is met, the value of the related pixel of the XRF image is written into this voxel. The same pixel of the XRF image is then set to zero. Therefore, such an XRF pixel is not written into other voxels laying behind the first detected material. An example of such XRF mapping onto surface of the reconstructed volume is demonstrated in Fig. 2.
2 Conclusions
It was proven that the fusion of XRF imaging and CT helps to identify the distribution of the various elements and relationships between the surface’s material composition and the geometry of the reconstructed volume. It is relatively easy to implement proposed method of the XRF mapping. It was shown that only six XRF images, taken during one rotation would be enough to cover the Pieta’s head fully, comparing one mapping and the reconstructed volume. A combination of XRF images with better statistics taken from different observation angles has to be done for better material identification/imaging. It will improve the mapping of the object’s surface in the areas which are not visible from some angles. Also new generation of the detector will used for future work.

Acknowledgements
The research was supported by Project No. DF11P01OVV001 of the Applied Research and Development of National and Cultural Identity Programme and by the project No. LO1219 under the National sustainability programme I of the Ministry of Education, Youth and Sports of the Czech Republic.

References