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Development of the detection system for imaging of spatial distribution of elements using the X-ray fluorescence method

Summary

Analysis of the spatial distribution of elements using non-invasive and non-destructive X-ray fluorescence spectroscopy has become a very important tool recently supporting the work of conservators and art historians. Elemental mapping of cultural heritage objects allows one to study spatial distribution of inorganic pigments present at the surface as well as in the invisible internal layers. The results obtained in such an investigation provide, for example, information about the state of preservation of the object, the quality of the conservation processes carried out in the past, broaden and update the available knowledge about the artist's technique and its workshop, and also support the determination of the provenance or authenticity of the investigated artworks.

The most popular technique used to obtain maps of the spatial distributions of elements is based on point-by-point scanning with an X-ray micro-beam collimated with a polycapillary optics. The spectrometers employing such a technique are characterized by high spatial and high energy resolution. Unfortunately, due to the type of the applied optics their applicability is limited only to flat objects. The relatively long measurement time is an issue, especially for large area objects. Therefore, an alternative technique based on the full-field imaging concept has been proposed.

The aim of this work was to develop such a full-field imaging system intended for mapping the spatial distribution of elements using the X-ray fluorescence method. In this dissertation a comprehensive description of system design along with a description of its individual components and operating principles is presented. The key components of the system are: the position sensitive detector based on the Gas Electron Multiplier (GEM) technology, front-end electronics based on the Application Specific Integrated Circuit (ASIC), and custom designed data acquisition system.

The energy resolution of the GEM detector is the critical parameter, which determines capability of the system to distinguish individual elements. Therefore the phenomena affecting the energy resolution have been studied carefully and proper measurement and calibration procedures have been worked out. Careful optimization process allowed us to achieve the system energy resolution at the level of 17% measured as Full Width at Half Maximum (FWHM) of K_α manganese 5,9 keV fluorescence line.

The second part of the dissertation is dedicated to development of the analysis methodology of data collected using the developed spectrometer. All implemented algorithms and necessary data correction procedures are described in details. For generation of final elemental maps, apart from the standard Region Of Interest (ROI) method, two factorization methods were used: Principal Component Analysis (PCA) and Non-negative Matrix Factorization (NMF). It is demonstrated that application of these methods can enhance significantly the capability of the developed system to identify particular elements.

Extensive validation of the developed data analysis procedures and demonstration of capabilities of the spectrometer based on measurements of several artworks and phantom type objects has been performed. The dissertation presents the measurement results for a few selected objects. Particularly noteworthy are the results achieved for non-flat objects, which confirm the large depth of field of the developed system and its capability of imaging objects with irregular, three-dimensional shapes without compromising of spatial resolution. The results presented in the dissertation prove the usefulness of the developed spectrometer in the area of cultural heritage investigation.

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