Die Sinaitischen Glagolitischen Sakramentarfragmente

The Sinaitic Glagolitic Sacramentary Fragments

F. Kleber, M. Diem, M. Lettner, M.C. Vill and R. Sablatnig
Institut für Rechnergestützte Automation
Technische Universität Wien
Favoritenstr. 9/1832, 1040 Wien
Tel.: +43-1-58801-18361, Fax: +43-1-58801-18392
E-mail: {sab,kleber,diem,vill,lettner}@prip.tuwien.ac.at Internet: http://www.prip.tuwien.ac.at

Zusammenfassung:
Dieses Projekt befasst sich mit der Digitalisierung von Manuskripten und der Bearbeitung des erfassten Bildmaterials durch Informatiker mit Spezialisierung auf Bildverarbeitung, und der anschließenden Editierung und Auswertung des Bildmaterials durch Philologen. Bei den zu digitalisierenden Objekten handelt es sich um mittelalterliche slawische Handschriften (z.B. Missale Sinaiticum, 11. Jhdt.). Bis zu den 90er Jahren war die Analyse von alten Handschriften eine Domäne von Geisteswissenschaftlern, jedoch ist die Bedeutung der Interdisziplinarität durch die technischen Möglichkeiten in den letzten Jahren gestiegen. Dies betrifft vor allem die Analyse von Palimpsest- und „schlecht lesbaren“ (z.b. durch Umwelteinflüsse) Texten, Internet Publikationen von Texten, Aufnahme von Wasserzeichen, usw. Zusätzlich ist es möglich, Handschriften durch Analyse der Schriftzeichen zu identifizieren und einem bestimmten Schreiber zuzuordnen. Die ersten Resultate werden in dieser Publikation präsentiert.

Abstract:
The project is a collaboration of philologists and computer scientists devoted to the recording, investigation and editing of medieval Slavonic manuscripts. The study of handwritten sources covers a wide field reaching from the examination of the physical body up to the text and its contents, make-up and condition. Until the 1990ties this was mainly a domain of the humanities. Technical scientists were engaged predominantly in the recording and conservation of valuable objects. During recent years, however, interdisciplinary work has gained ground, concentrating not any more on a few special tasks, like the development of Optical Character Recognition (OCR) software, but comprising a growing amount of relevant items: the description of manuscripts, the digital-publication of texts, the imaging and restoring of watermarks, palimpsests and other “latent” texts, or a thorough description of writing systems and the identification of individual handwriting. First results of the project are presented in this paper.

Introduction

Digital Imaging for ancient documents has gained significant interest in recent years, and it may be expected that in the long run the decipherment, study and editing of such sources will be done predominantly based on images; a way that relieves the originals and makes their investigation independent of the place of preservation. Additionally a more precise and less time-consuming analysis of the manuscripts through automatic image analysis is possible. Furthermore, digitalization permits a lossless storage of the contents of a document. To provide information that is not visible with the human eye, spectral imaging methods have to be applied. Therefore, digital cameras sensitive to an extended spectral band (e.g. InfraRed (IR) CCD cameras, Vidicons) have to be used. Multispectral imaging techniques in combination with digital image processing allows on the one hand enhancing the readability of “hidden” texts (e.g. palimpsests, vanished or damaged text due to environmental effects like mold, humidity or fading out of ink, see

Rapantzikos & Balas, 2005; Salerno et al., 2007) and on the other hand automated investigation of the structure and content of the manuscripts. Multi- and hyper-spectral imaging has been used in a wide range of scientific and industrial fields including space exploration like remote sensing for environmental mapping, geological search, medical diagnosis or food quality evaluation. Recently, the technique is getting more and more applied in order to investigate old manuscripts. A prominent representative of multispectral imaging in the domain of analysing ancient documents is the Archimedes Palimpsest (Easton et al. 2003).
The objects to be edited in this project are two Glagolitic manuscripts with Cyrillic and Greek additions of the so-called classical Old Church Slavonic corpus, belonging to the new findings made in 1975 at St. Catherine's monastery on Mt. Sinai (Codd. Sinaitici slav. 1/N & 5/N). Since photographic techniques in the visible range (film, digital camera) have proven to be insufficient with the objects given, spectral imaging has to be applied
The multispectral image acquisition system, as well as the non-destructive measurement techniques used in the context of this project are described in the following section.

Multispectral Acquisition of Ancient Documents

The human eye is sensitive to electromagnetic radiation in-between a wavelength range of approximately 380nm (corresponding to blue) to 780nm (corresponding to red). Digital cameras (e.g. Charge Coupled Device (CCD) cameras) can be used to record images beyond the range of the human eye, thus providing additional information. In the field of the investigation of ancient documents digital cameras that are sensitive to the UltraViolett (UV, approx. 200-400nm) and the Near InfraRed (NIR, approx. 780-1400nm) are used. Since the spectral response of silicon based CCD camera ends at 1200 nm, IR Video Cameras with tubes (Vidicon) with a sensitivity up to 2200 nm are still an alternative to CCD cameras (Hain et al., 2003; Mairinger 2003). Optical filters can be used to capture a specified wavelength range.

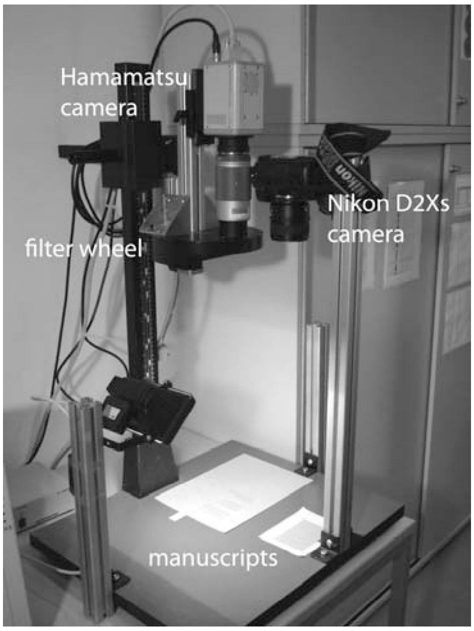

Figure 1: Setup of the Acquisition System

The associated imaging techniques are called IR reflectography, UV reflectography and UV fluorescence. Suitable filters are listed in Mairinger, 2003. IR reflectography (de Boer, 1970) is a technique, which is capable to visualize layers of paintings (underdrawings) below the visible surface. The effect of IR reflectography is a „*lower absorption of the layer and reduced scattering due to pigment particle size smaller than the NIR wavelength*" (Falcone et al., 2007). Thus, IR reflectography can be used to distinguish different text layers. A detailed description of infrared reflectography and the mathematical formulation of the reflection is described in Hain et al. (2003) and Mairinger (2003).

UV Fluorescence can also be used to enhance the readability of palimpsest texts, since "*old paint or varnish layers emits more fluorescence light comparing to newly applied materials (repainting or retouching area)*" (Hain et al., 2003). Fluorescence is luminescence that is the emission of one or more photons by an atom (or molecule) that is caused by absorbing a certain amount of electromagnetic radiation. The emitted radiation after excitation by a UV source of radiation has either a shorter, a longer or equal wavelength compared to the incident wavelength (Mairinger, 2003). Easton et al. (Easton et al., 2003) deal with multispectral imaging techniques, which are applied to the Archimedes palimpsest. To illuminate an object with UV radiation a HQV 125 lamp with a wavelength peak of 375nm can be used. An alternative is the use of LEDs as a narrowband light source, which reduces the amount of incident light to the painting/manuscript which follows the conservation goal to minimize the incident light dose (Barry, 2007).

Figure 1 shows the acquisition setup used in our project. One design goal was, that the entire system has to be transportable, since the manuscripts are located at St. Catherine's monastery/Sinai, and the entire equipment has to be carried to Egypt/Sinai. To switch between different filters a filter wheel can be used. A different possibility is a filter, in which the spectral transmittance can be controlled electronically (e.g. Liquid Crystal Tuneable Filters, LCTF, see (Tominaga & Okajima, 2000). In our setup a filter wheel, with the following filters embedded is used:

- Short-pass filter 400 nm to capture UV-reflectography images
- Long-pass filter 400 nm to capture UV-fluorescence images
- Long-pass filter 800nm to capture IR-reflectography images
- Band-pass filters with a peak frequency of 450, 550, 650 and 780nm to capture the colour channels (Red, Green and Blue) in the visible range of the spectrum

The camera belonging to the filter wheel is a monochrome Hamamatsu C9300 IR CCD camera with a spectral sensitivity of 330-1000nm and a resolution of 4000 x 2672 px. To capture colour-images (and also the UV-fluorescence images) each page of a manuscript is additionally recorded with a Nikon D2Xs camera. The alignment of the two cameras is shown in Figure 1. These setup leads to a spatial resolution of approximately 500 dpi. Since every folio is captured with both cameras, a shift of the manuscript page between the cameras is necessary. Therefore, a registration of the images is done. Both Nikon images are coarsely registered to the reference image (Hamamatsu Camera, no filter) by an affine transformation. This compensates the rotations caused by repositioning the manuscript pages. The feature matching is done using rotationally invariant local descriptors of the Scale-Invariant Feature Transform (SIFT) (Lowe, 2004). Having aligned both Nikon images coarsely to the reference image using adapted SIFT features and a global affine transformation, a template matching and a subsequent local transformation is performed in order to correct non-rigid distortions caused by changing page curvatures. Transformations using polynomials of order n are defined by at least n+1 parameters, which results in a complex similarity functional that has many local optima. To overcome this problem a local mapping function is applied. The local weighted mean method (Goshtasby, 1988) is a local sensitive interpolation method. It requires at least 6 control points which should be spread uniformly over the entire image. Polynomials are computed by means of the control points. Thus, the transformation of an arbitrary point is computed by the weighted mean of all passing polynomials. Besides, a weighting function is defined which guarantees that solely polynomials near an arbitrary point influence its transformation. A more detailed explanation of the registration method is presented in Diem et al. (2007).

Image Enhancement

The enhancement of the readability in historic texts written on parchment is necessary, if the manuscripts are partially damaged due to environmental effects like mold, air humidity or water and consequently hard to read. The readability enhancement is based on a spectral and spatial analysis of the multivariate image data by Multivariate Spatial Correlation (Wartenberg, 1985). The main advantage of the method is that especially the text regions are enhanced which is provided through the generation of a mask image. This mask is based on automatically deriving the ruling scheme of the text pages. A detailed explanation of the enhancement is presented in Lettner et al. (2008).

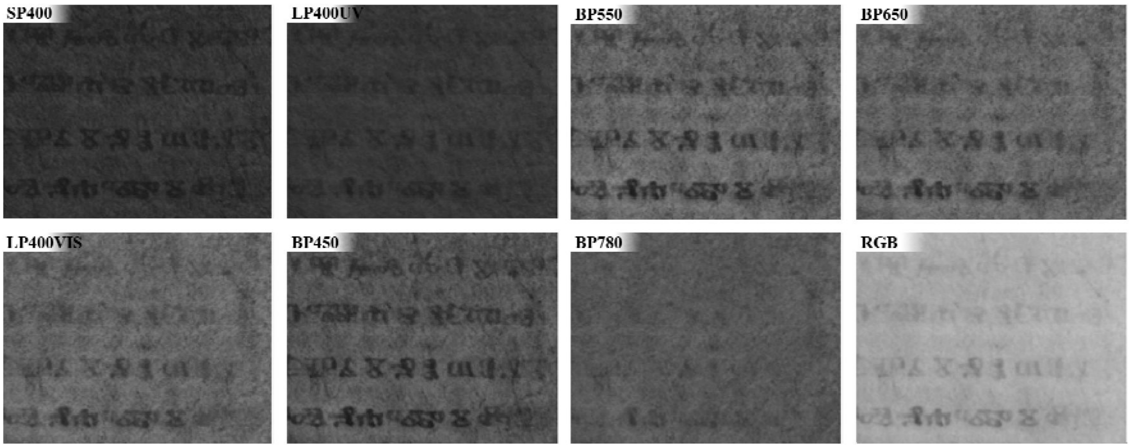

Figure 2: Multispectral Images

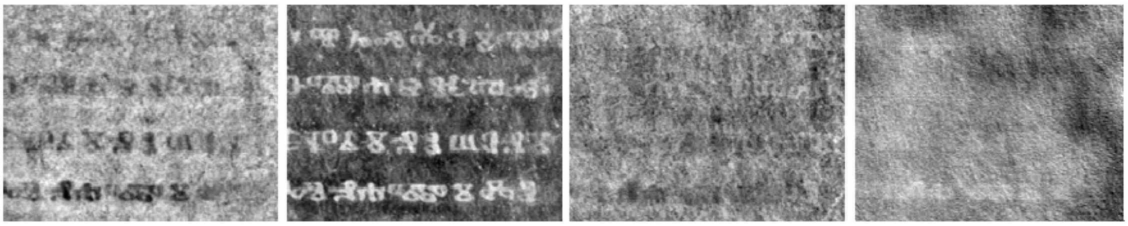

Figure 3: MSC results

Figure 2 shows the input images of a part of a page of the Missale Sinaiticum in different spectral bands. The resulting images after the image enhancement are presented in Figure 3. Regarding the input images in Figure 2 it can be seen that the characters especially in the upper left corner and in the middle of the second and third row are hardly visible. In the second band obtained after the enhancement the visibility of the characters is clearly enhanced, see Figure 3.

Document Analysis

The following subsections describe the algorithm for analysing the writing as well as the ruling.

Stroke Analysis

In our approach we combine linguistic and computational methods. The linguistic basis consists of a precise formal (not: functional) and comprehensive catalogue of scriptural features, which is not designed only for the Glagolitic, but for any kind of script. This catalogue is divided in two superordinate levels of graphetic character description, static and dynamic. The former characterizes the visual shape of the letter, i.e. the state as it is, whereas the latter focuses on the production and consecutiveness of how it was made. For the present purpose only some static features have been considered, and the linguistic definitions have been adapted to the requests of machine handling. This revised list of graphetic attributes is the starting point from which - in the final end – we will single out those features for computer processing that are able to distinctly mark a character in order to facilitate script reconstruction, automatic amendments of (incompletely preserved) letters, and OCR.

Accordingly, we introduce means to dissect each character into analyzable segments for further processing: nodes and strokes. Nodes are defined as crossings of minimum three line segments, and each line segment or streak coming from a node constitutes a single element and is defined a static stroke. These elements are countable and, thus, give first empirical information on the character. Furthermore, these segments form the basis for the further application of other features, which partly apply not to the character as a whole, but only to an individual segment or several segments of a single character.

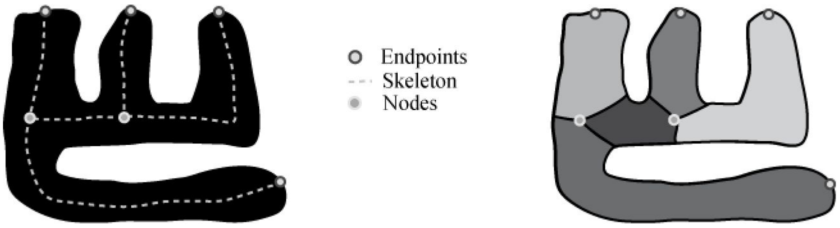

Figure 4: Schematic view of a Glagolitic character. On the left, a segmented character is shown with skeleton, nodes and endpoints. The right side shows the character's static strokes

Figure 4 shows a schematic view of a Glagolitic character with a skeleton. The skeleton is divided into branches, which either go from an endpoint to the nearest junction on the path or consist of paths between junctions. Each part of the character, in which one skeleton branch is embedded, is defined as a static stroke. Figure 4 (right side) shows a Glagolitic character with disassembled static strokes. The numbers of the static strokes and nodes are obtained directly from the graph representation of the skeleton. The explanation of the analysis of strokes as well as the used features for calculating graphitic attributes of static strokes are listed in Vill et al., 2008.

Ruling Estimation

The algorithm developed within this project estimates the ruling of degraded manuscript folios. For that purpose the baseline of the text is taken as ground-truth for the ruling scheme. Since the ruling defines the position of the text within a page, it can be used for layout analysis and as a basis for the enhancement of the readability. Furthermore, information about the scribe (hand) of the manuscript, its spatiotemporal origin can be gained by analyzing the ruling (Leroy, 1976).

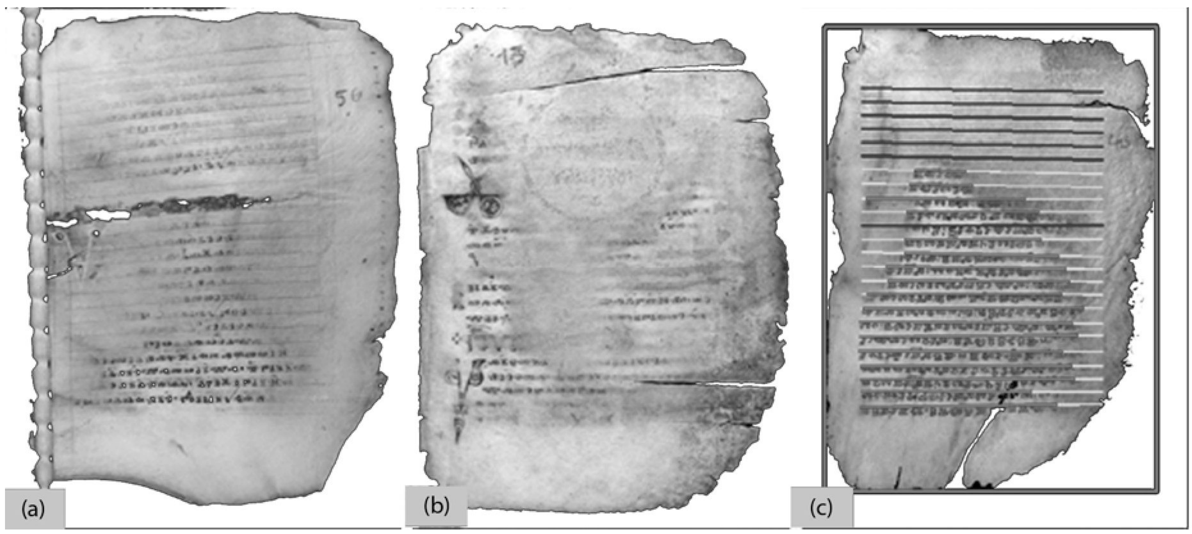

Figure 5: (a) recto side of a folio with original ruling (still visible). (b) recto side of a folio (ruling not visible due to degradations). (c) estimated ruling of a page

To estimate the ruling text lines are extracted, and the calculated baselines of the text are assumed as ground-truth of the ruling scheme. In regions of pages, where the text has vanished, the a priori knowledge of the ruling (Miklas, 2000) is used to extend the calculated ruling. The algorithm can be improved if the original ruling or (visible) parts of it may be extracted, and the results be applied for the rejection decision of single baselines calculated on mere text information. Figure 5 (a) shows a page of the manuscript where parts of the original ruling are still visible, while in Figure 5 (b) a degraded page with a vanished ruling (due to environmental conditions) is shown. To be independent from the condition of the ruling of a page, the text information is chosen as basis for the ruling estimation. Figure 5 (c) illustrates a result of the ruling estimation of a manuscript page. A detailed description of the method is presented in Kleber et al. 2008.

Conclusion

The benefit of multispectral imaging for the investigation and the analysis of ancient manuscripts was presented in this paper. Multispectral imaging supports the investigation of ancient manuscripts where the text is hardly visible in conventional RGB images or for the human eye. Since almost all of the ca. 80 fol. of the Missal (5/N) are in a deplorable state, this pages cannot be deciphered without the aid of multispectral imaging. For the further development of the images, algorithms to analyse the ruling of the pages and also for stroke analysis have been presented. While image acquisition and enhancement have been treated in computer science and serve for a better readability of latent texts, so far their results had to be deciphered and analyzed by conventional philological methods. Consequently, the computer aided script description and recoverment is another technical innovation in this project. This will open new perspectives for palaeographical and graphemic analyses of alphabetic (phonographic) writing systems.

References

Barry, W. A. C., accessed 2007. Led Imaging of the Archimedes Palimpsest. *http://archimedespalimpsest.org/imaging_experimental3.html.*

Burmester, A., Cupitt, J., Derrien, H., Dessipris, N., Hamber, A., Martinez, K., Muller, M., & Saunders, D., 1992. The Examination of Paintings by Digital Image Analysis. In *Proc. 3rd International Conference on Non-destructive Testing, Microanalytical Methods and Environment Evaluation for Study and Conservation of Works of Art*. 210–214.

de Boer, J. V. A., 1970. Infrared Reflectography. - A Contribution to the Examination of Earlier European Paintings. *Ph.D. thesis*, Univ. Amsterdam.

Diem, M., Lettner, M., & Sablatnig, R., 2007. Registration of Multi-Spectral Manuscript Images. In *Proceedings of the 8th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST07*. Brighton, UK, 133–140.

Easton, R., Knox, K., & Christens-Barry, W., 2003. Multispectral Imaging of the Archimedes Palimpsest. In *32nd Applied Image Pattern Recognition Workshop, AIPR 2003*. Washington, DC: IEEE Computer Society, 111–118.

Falcone L., Bloisi F., Califano V., Pagano M., Vicari L., 2007. Near infrared reflectography for deciphering obscured (whitewashed or ablated) epigraphs. Journal of Physics (40)2007, 5547-5552.

Goshtasby, A., 1988. Image Registration by Local Approximation Methods. *Image and Vision Computing*, 6, 255–261.

Hain, M., Bartl, J., & Jacko, V., 2003. Multispectral Analysis of Cultural Heritage Artefacts. In *Measurement Science Review*. vol. 3.

Kleber, F., Sablatnig, R., Gau, M., Miklas, H., 2008. Ruling Estimation for Degraded Ancient Documents Based on Text Line Extraction. In *Proc. of 2nd EVA 2008 Conference, Digital Cultural Heritage – Essential for Tourism*, Vienna, Austria, 79-86.

Leroy, J., Paris, 1976. Les types de reglure des manuscrits grecs.

Lettner, M., Kleber, F., Sablatnig, R., Miklas, H., 2008. Contrast Enhancement in Multispectral Images by Emphasizing Text Regions. In Proc. of the 8th IAPR International Workshop on Document Analysis Systems (DAS 2008), Nara, Japan, 225-232.

Lowe, D. G., 2004. Distinctive Image Features from Scaleinvariant Keypoints*. International Journal of Computer Vision*, 60(2), 91–110.

Mairinger, F., 2003. Strahlenuntersuchung an Kunstwerken. Berlin: E.A. Seemann.

Miklas, H., 2000. Zur editorischen Vorbereitung des sog. Missale Sinaiticum (Sin. slav. 5/N). In H. Miklas, V. Sadovski, & S. Richter (Eds*.), Glagolitica - Zum Ursprung der slavischen Schriftkultur*. (ÖAW, Phil.-hist. Kl., Schriften der Balkan-Kommission, Philologische Abt. 41), pp. 117–129.

Rapantzikos, K. & Balas, C., Sept. 2005. Hyperspectral Imaging: Potential in Non-destructive Analysis of Palimpsests. *Image Processing, 2005. ICIP 2005. IEEE International Conference on*, 2, II–618–21.

Salerno, E., Tonazzini, A., & Bedini, L., 2007. Digital Image Analysis to Enhance Underwritten Text in the Archimedes Palimpsest. *International Journal on Document Analysis and Recognition*, 9(2), 79–87.

Taubert, J., 2003. Zur kunstwissenschaftlichen Auswertung von naturwissenschaftlichen Gemäldeuntersuchungen. München: Anton Siegel.

Tominaga, S. & Okajima, R., 2000. A Spectral-Imaging System and Algorithms for Recovering Spectral Functions. Image Analysis and Interpretation, 2000. *Proceedings. 4th IEEE Southwest Symposium*, 278–282.

Vill, M.C., Gau, M., Miklas, H., Sablatnig, R., 2008. Static Stroke Decomposition of Glagolitic Characters. In *Proc. of 2nd EVA 2008 Conference, Digital Cultural Heritage – Essential for Tourism*, Vienna, Austria, 95-102.

Wartenberg, D., 1985. Multivariate Spatial Correlation: A Method for Exploratory Geographical Analysis. *Geographical Analysis*, 17(4), 263–283.

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