IMAGE PROCESSING AND UV/VIS/IR-REFLECTOGRAPHY WITH BANDPASSFILTERS. THE MAKING VISIBLE OF WASHED OR RUBBED WRITING IN MEDIEVAL MANUSCRIPTS ANALYSIS OF UNDERDRAWINGS IN BOOK PAINTING. PRESENTATION OF THE PRINTED DIGITIZED IMAGES.

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Investigations of old manuscripts and documents should be totally non-destructive. New UV/Vis/IR-reflectography techniques in combination with bandpass filters and with image processing makes it possible to distinguish inks and colour materials and can make faded or rubbed writing and underdrawings visible.

Documents and autographs in archives and libraries are not infrequently damaged (washed out and rubbed) by poor storage conditions or by the disastrous influence of fire, water etc. in the past. The paper has been damaged, the ink colours are no longer visible and the text or the images have become illegible. Especially at the beginning 20th century there was great enthusiasm for experiments in making faded inks visible through the application of chemicals which originally enhanced the script, but have since darkened and destroyed the writing support. New techniques should be totally non-destructive. A combination of different optical and electronic techniques make this possible.

The illumination of an object with light can provoke three different effects: absorption, reflection and sometimes also fluorescence. Every material has its specific characteristic; for example if the ink absorbs the light and the background reflects it, the contrast of writing and support is so different that we are able to read the text. If the ink is faded or rubbed but even the faintest traces of it remain on the surface of paper or parchment, with the use of monochromic light it is possible to find the exact wavelength where the contrast between ink and support is great enough that the script appears darker or lighter than the background. Then the script is again visible and can be read.

In the visible range (Vis) the various colors can be observed by naked eye, but in the Ultraviolett (UV) or Infrared (IR) ranges the wavelengths can be quantified only with a detector. For the UV and VIS (200 - 780nm) and for the near range of the IR (750 - 1900nm) two different videocameras (HAMAMATSU C2400-03/05) can be used. This method can be applied to analyze materials of a painting or to distinguish between inks or other drawing materials[1]. It is useful to make

[1] For the non-destructive (i.e. without any samples) analysis of colour and ink materials three other techniques are already in use: XR-diffractometry, IR-spectroscopy and colour spectroscopy, see: *Robert Fuchs*, Zerstörungsfreie Untersuchungen an mittelalterlicher Buchmalerei - eine wissenschaftliche Herausforderung. Tagungsband zum Symposium für Zerstörungsfreie Prüfung von Kunstwerken, 19./20. November 1987. Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V. Berichtsband 13, Berlin 1988, pp. 120-127.
Other techniques need samples from the original, which is very problematical from the conservational point of view: for example the RAMAN-spectroscopy, see: *Bernard Guineau, Jean Vezin*, Etude technique des peintures du manuscrit De laudibus sanctae crucis conservé à la Bibliothèque Municipale d'Amiens (Amiens 223). In: Scriptorium 46, 1, Bruxelles 1992, pp. 224-237.
The new reflectography technique allows the non-destructive 2-dimensional material analysis: *R. Fuchs, R. Mrusek, D. Oltrogge*: Spektrale Fenster zur Vergangenheit. - Ein neues Reflektographieverfahren zur Untersuchung von Buchmalerei und historischem Schriftgut, Naturwissenschaften 82.2, Heidelberg 1995, p. 68 -79, esp. p. 73, fig. 1, 2

underdrawings in book illumination visible[2] or to examine faded texts[3]. The analysis includes the ultraviolet (UV), the visible and the infrared (IR) ranges. In all cases problems can be solved by analyzing separate sections of the spectrum. To realize such a segmentation of the spectrum, bandpass filters can be applied (Fig. 1).

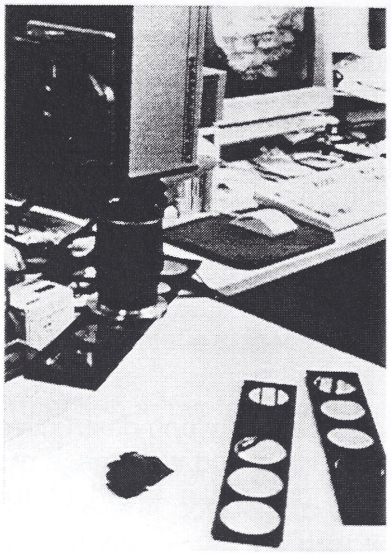

Fig. 1. Under the objective of the IR-camera a set of bandpass-filters is mounted.

1 Method

The object is illuminated with light of low intensity. Depending on the problem we use various light sources, which give access to the different parts of the spectrum. A tunable device is applied, which emits white light or alternatively monochromatic light in all ranges of Vis and in some bands of UV and IR. Barrier filters can be used to separate narrow regions of IR for illumination. For the IR, red light bulbs of the type employed in photographic laboratories are also used.

The intensity of light reflected (?) by any material will alter as a function of the wavelength. In each case where desired and disturbing effects appear simultanously, they can be separated if they show different responses to illumination by light. The images are recorded in a range from UV (>200nm) to IR (<2000nm) by using two different electronic tube cameras. We apply at least 25 optical bandpass filters to divide the spectrum of the reflected light into narrow bands of 60 to 120nm[4]. A chosen detail of an object is illuminated and recorded with different filters. This leads to a series of images. The signals are digitized and the images can be stored on a portable PC. The quality of the images can be improved by digital image processing. This method works with portable instruments, and investigations can be done outside the laboratory in museums, libraries and archives.

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2 *Robert Fuchs, Doris Oltrogge*, Naturwissenschaft und Stilkritik - Handschriften aus dem Umkreis des Registrum-Meisters. In: Kunsthistoriker, Mitteilungen des Österreichischen Kunsthistorikerverbandes, Jg. VIII (Sondernummer) 1991, p. 96-104. *Doris Oltrogge*, "Materia" und "ingenium". Beobachtungen zur Herstellung des Egbert-Codex. In: Egbert - Erzbischof von Trier. Hrg. v. F. J. Ronig unter Mitarbeit von A. Weiner und R. Heyen. [=Trierer Zeitschrift, Beiheft 18], Trier 1993, Vol. 2, p. 123-52. *Robert Fuchs, Doris Oltrogge, Ralf Mrusek*: Eine Galerie des Unsichtbaren. Spektrum der Wissenschaft, Juni 1995, p. 85 - 89. *Robert Fuchs, Doris Oltrogge*, Neue Untersuchungen an mittelalterlichen Handschriften. In: Rhythmus und Saisonalität. Akten des 5. Symposiums des Mediävistenverbandes. Hrg. P. Dilg, G. Keil, D.-R. Moser. Sigmaringen 1995, p. 327 - 345.

3 *Robert Fuchs, Ralf Mrusek, Doris Oltrogge*, Die Entstehung der Handschrift - Materialien und Maltechnik. In: Petrus von Ebulo, Liber ad honorem Augusti sive de rebus Siculis, Eine Bilderchronik der Stauferzeit aus der Burgerbibliothek Bern. (Ed. Th. Kölzer und M. Stähli), Sigmaringen 1994, p. 275 - 285. *Ralf Mrusek*, Reflections reveal faded secrets of ancient books. Opto & Laser Europe 36, Bristol 1996, p. 11.

4 *Fuchs et al.*, Spektrale Fenster (supra note 1), p. 71, Tab. 1.

2 Image Processing

The interpretation of images of ancient objects in art historical research can be assisted by a digital image processing system[5]. Thus images produced by IR cameras and optical filtering will lead to a better understanding of the manufacturing process and the history of an object, but the method has some disadvantages due to the technique. Therefore these disadvantages have to be corrected by developing the necessary software programs. The available image processing software can be used to optimize the image acquiring procedure and to improve the stored images in additional processing steps[6].

2.1 Image Acquiring

In digital image acquisition noise effects which interfere with the signal are introduced by the electronic components of the system. They have a recognizable effect, because we are working with weak signals. For illumination one has to be careful in choosing the light source. Light of lower intensity should be applied to avoid heating fragile surfaces. But the smaller the intensity of light for illumination, the smaller the response of light from the pigments and inks. That means that the light which enters the camera is already limited in intensity. In addition the optical filter process will cut only a narrow band of the whole light intensity. This weak signal which reaches the detector has to be amplified electronically. But in the same way the signal is amplified, the noise of the image acquiring system is increased. Consequently beside the signal the noise is recognizable in the resulting images. It is desirable to suppress the noise interference in advance during the acquisition process by digital image processing.

We have therefore implemented the following acquisition procedure. The electronic noise changes in time; one can thus eliminate it by storing some images in a time interval and carrying out an averaging process. To realize this process a series of up to 16 images within about 3 seconds will be acquired and the average of these images shows a reduction of the signal/noise ratio.

By this operation the noise in the resulting image in comparison to that in an immediately frozen (?) image can be enormously reduced. To have an idea of the amount of noise reduction, we have measured it with the Fourier transformation technique[7] and found that an average over 16 images is sufficient even for the very weak signals in the upper range of the IR-camera (1700 - 1900nm). The OPTIMAS (Ver. 6.0) software is used for this purpose. This software can be programmed and has many acquired functions. It is normally used for medical purposes for the automatic calculation of blood cell density etc.

2.2 Image Enhancement

The digital images stored on a hard disk are processed in several additional steps. The images recorded by the camera system have low contrast and need to be sharpened to enhance contours and to amplify the visibility of image details. For this purpose we use different image processing software: Optimas, ADOBE Photoshop, MGI Photosuite and ACDSee32.

In library research projects the images have to be prepared for analysis by a human expert. In contrast to industrial image processing, which is implemented in a mechanized visual system to test the quality of serial product manufacturing, we are working with unique objects. But nobody knows in advance which details should have been expected in an image. Mostly we are using interactive procedures in which an historian or art historian or a philologist has control over the successive processing steps.

In the first image processing step the contrast of an image will be increased. That do not means that the images acquired by the camera use the entire dynamic range of the image processing and

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[5] Andreas Burmester, F. Bayerer, Towards improved infrared reflectograms. Studies in Conservation 38.3, OOO 1993, p. 145 - 152.

[6] *Peter Haberäcker*, Digitale Bildverarbeitung, C. Hanser Verlag, 3. Aufl., OOO 1989. *Bernd Jähne*, Digitale Bildverarbeitung, Springer Verlag, Heidelberg 1990.

[7] Robert Fuchs, Ralf Mrusek, New Methods of Reflectography with Special Filter und Image Processing Techniques: Examination of Materials, Writings and Underdrawings, in: Optical Technologies in the Humanities, Hg. D. Dirksen, G. von Bally, Optics Within Life Sciences, OWLS IV, Berlin 1997, S. 108 - 118.

[7] E. O. Brigham, FFT - Schnelle Fouriertransformation, München/Wien 1989.

display system. Therefore the images should be scaled between the minimum and maximum of the image.
In further processing steps we use edge enhancement procedures to sharpen contours in the image. We have had good experience with unsharp mask filtering which is based on a traditional photographic technique in which a negative and the blurred positive image are combined and exposed on a high contrast film. In the software realization one is able to control how many pixels in the neighborhood of a pixel at the boundary of a contour are processed. The effect of the filter procedure is that the contrast is increased, particularly at the boundary pixels of a contour line.

2 Application in Humanities (library reseach)

2.1 Text investigation

In a number of ancient manuscripts the text has become unreadable for the naked eye. Sometimes a part of a text has been overwritten or covered to make it unreadable. Another problem is the ageing of manuscripts. The ink has corroded, washed or faded out, or the surface of the manuscript has darkened by age or dirt. Nevertheless, often different inks as well as ink and writing support (paper, parchment etc.) show different remission (reflection?) characteristics. By using bandpass filters it is possible to separate these characteristics and to show only the reflection of the ink. Thus it is possible to make unreadable texts readable once again. Fig. 2 shows a leather fragment from Elephantine, Ancient Egypt (2nd half of 5th cent.)[8], which was published as an Aramaic text, because nobody could read it[9]. The image is recorded in the range of visible light, illuminated with infrared light and recorded with a filter of 950nm so that the text can be read (Fig. 3). It is a Demotic text, and, in addition, even a palimpsest which runs transversal to the later text and informs us about a list of names was discovered[10].

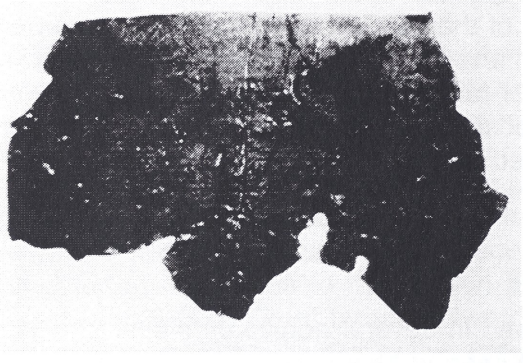

Fig. 2. Leather fragment from Elephantine 5th cent. under visible light (PMB P13443).

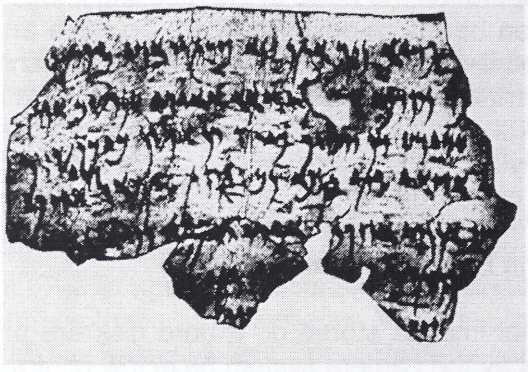

Fig. 3. Leather fragment (fig. 2) under infrared light of 950nm.

Fluorescence techniques have been used for a long time to read faded texts. The manuscript is illuminated with UV light, and the response to its stimulus is observable as emission of visible light. The UV camera makes an additional approach possible. Reflections which are not visible to the human eye can be recorded. Bandpass filters in this region suppress effects belonging to the interaction of the material with visible light. On the other hand, the time of exposure to the UV light can be considerably reduced by digital image recording (at least to 3 sec). This is important for the conservation of precious manuscripts[11].
In July 1999 we were invited to investigate the almost totally washed out manuscripts in the Archive of the Opera del Duomo in Florence. The disastrous flood of 1966 in Florence had severely damaged many manuscripts and illuminated books. 15 years later the texts of the most famous archival codices on the work of the Opera del Duomo are being transcribed and put in a database which will soon be available on Internet. But some of the books even could not be read,

[8] Pergamon Museum Berlin, P 13443
[9] *Eduard Sachau*, Aramaeische Papyrus und Ostraca, Leipzig, 1911.
[10] *Bezalel Porten*, Textbook of Aramaic Documents from Ancient Egypt, Vol. 4, Winona Lake (Ind.), in prep.
[11] *Fuchs et al.*, Spektrales Fenster (supra note 1), p. 75

even with the help of the UV fluorescent lamp. With our technique it was possible to make nearly all the texts visible, and the images were digitized and stored in the database; they too will be accessible via Internet. To get a better resolution a series of 5 images were acquired from every page. One page could therefore digitized under UV-light (366nm) within 30 sec (3 sec for each image) and was exposed very short time to the UV-light. The result was astonishing. Even on blank pages where the ink was washed out totally the reflection images can now be deciphered very easily. Digitization from film or directly from the original is normally made with white light and would in this case not have shown the text (Fig. 4). Only the acquisition with our bandpassfilter-reflectography technique made the text available for the reader.

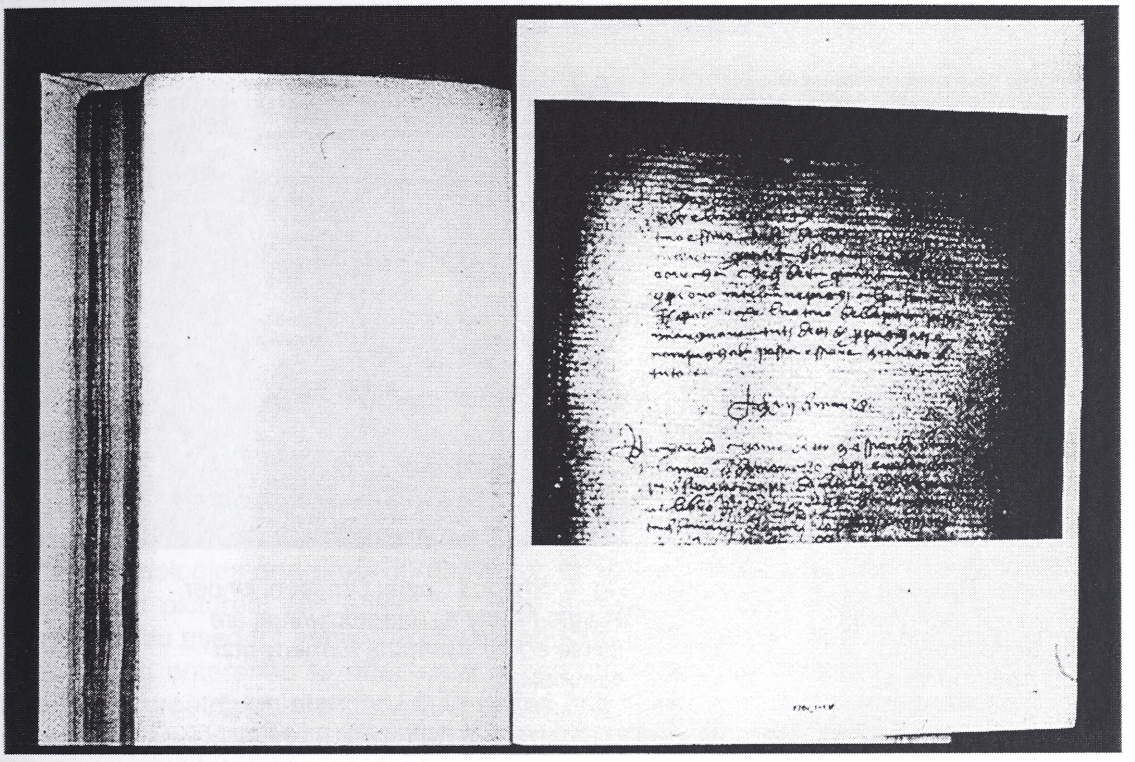

Fig. 4. Opera del Duomo Firenze, II-2-2, f. 76v. Left: original page shows the washed out text; right: print of the digitized image by reflection under 366nm.

2.2 Material analysis

The reflectography method with bandpass filters can also be used as a tool for material analysis. Different writing materials show different properties, especially in the range of IR. Application of bandpass filters will show that inks, which in a certain bandpass region absorb light in the same manner, can show differing properties in another range. As a function of the wavelength of remitted (reflected?) light the appearance of a text will change. This can be demonstrated through the images of three texts written with iron gall ink, blackthorn ink and lamp black[12]. In a similar manner a varying remission (reflection?) of different painting materials can help to analyze pigments in medieval book illumination and other paintings[13].

In comparison to common spectrometer methods, reflectography offers an additional advantage: besides information about the value of light intensity, the displayed image contains information about the local distribution (two-dimensional information) of the materials.

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[12] *Fuchs et al.*, Spektrales Fenster (supra note 1), p. 73, fig. 1.
[13] *Fuchs et al.*, Spektrales Fenster (supra note 1), p. 73, fig.2

2.3 Underdrawings

The filter technique is also a powerful tool in the examination of underdrawings. Sometimes there are considerable differences between the drawing and the completed painting[14]. Whether the drawing materials are recognizable or not on the digital image depends on the property of the materials covering the drawings. We found that in a range where certain drawing materials are observable some painting materials will become transparent, but others are impenetrable to the light in the chosen bandpass region. Therefore, multiple series of images recorded with different bandpass filters have proved useful in obtaining the most complete information on the underdrawings. In some cases different drawing materials have been used in one picture. The use of bandpass filters permits the concentration on one material in order to make it visible and the suppression of the others' effect in the digital image (Fig. 5, 6).

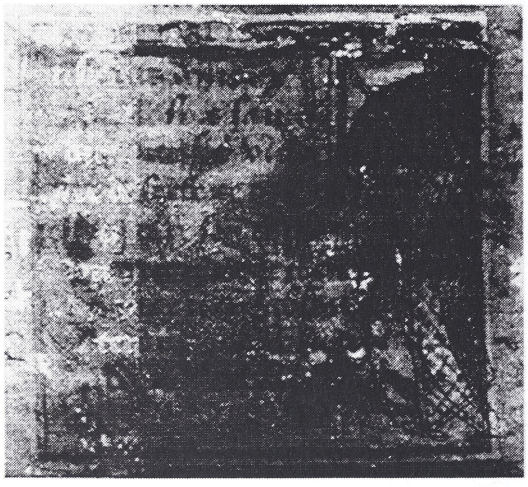

Fig. 5. Phebus Codex Dresden. The totally washed out manuscript small rests of an underdrawing can be observed from the verso.

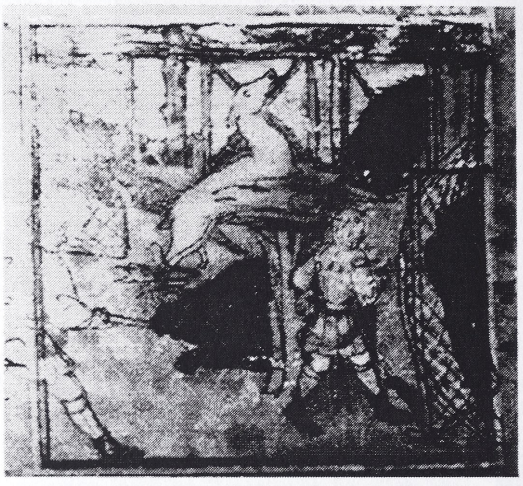

Fig. 6. Phebus Codex Dresden. Under IR-light nearly all underdrawings are visible and present the formerly rich illumination.

2.4 Exposition of text information and painting sequence of a scriptorium

The digitized images of underdrawings of reconstructed text can easily presented in demonstrations. The digitized information can be printed and calculated and enhanced with image processes, so that the presentation even on large posters is possible. For the amelioration of the resolution of a picture, a series of different images were made with a small overlapping border. An additional software program allows us to combine automatically this series of Tiff-images into a bigger picture. So even large panel paintings or book paintings can acquired and printed in a reasonable resolution. The investigation of underdrawings, painting technique and colour material permits the reconstruction of the workshop practice of a scriptorium or a master and the prints can be shown in an exposition of directly in the internet or on a CD-ROM.

Abstract:
Investigations of old manuscripts and documents should be totally non-destructive. New IR/UV/Vis-reflectography techniques, combinations of bandpass filters with image processing allows distinction amongst inks and colour materials and can make faded or rubbed writings and underdrawings visible. The digitized images can be put directly on a CD-ROM or printed in a database which also can be used in Internet or presented in an exposition.

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[14] *Fuchs et al.*, Eine Galerie (supra note 2), fig. 3, 4, 5.