Deutsche Gesellschaft für
Zerstörungsfreie Prüfung e.V.

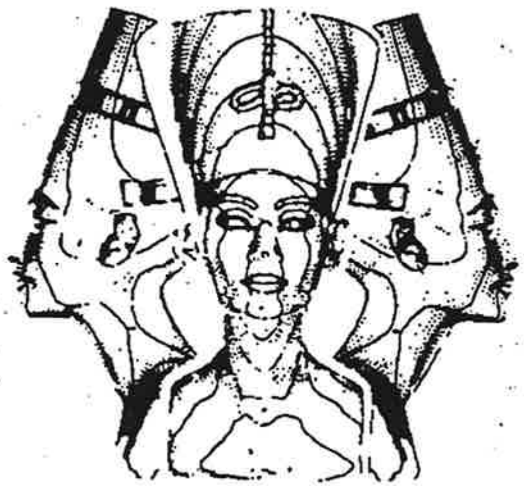
Berichtsband 45, Teil 1

BAM
Bundesanstalt für
Materialforschung
und -prüfung

SMB
Staatliche Museen
zu Berlin
Preußischer Kulturbesitz

AIPnD
Associazone Italiana
Prove non Distruttive
Monitoraggio Diagnostica

ICR
Istituto Centrale
per il
Restauro



4th International Conference
Non-Destructive Testing of Works of Art

4. Internationale Konferenz
Zerstörungsfreie Untersuchungen an Kunst- und Kulturgütern

Berlin 3. - 8. Oktober 1994

Deutsche Gesellschaft für Zerstörungsfreie Prüfung e.V., Berlin
4. Internationale Konferenz Zerstörungsfreie Untersuchungen an Kunst- und Kulturgütern
4th International Conference on Non-Destructive Testing of Works of Art

A. Burmester, F. Bayerer, München

Remote imaging spectroscopy of drawings

Berührungsfreie bildgebende Spektroskopie an Handzeichnungen

INTRODUCTION

In interdisciplinary cooperation with the humanities, scientific examinations help to understand works of art. Today, a fast growing number of analytical methods yield bits and pieces of scientific information concerning the objects material nature. However, the integrity of the works of art force scientists not to take samples but to use non-destructive methods. This is especially true for drawings (drawing material on paper) from which samples can not be usually taken. This contribution aims to demonstrate the so-far unexplored potential of remote sensing spectroscopy in the investigation of drawing materials.

A conventional system for infrared-reflectography (system I) consists of a light source, the object under investigation, a video-camera sensitive in the Near-Infrared (NIR), a photographic lens and a long-pass filter. We described in an earlier contribution (1) how to improve the lighting and the image quality by narrow band filtering and (2) how to mosaic large size digital infrared images [1]. Some years ago, one of us (A.B) used single spot measurements by diffuse reflectance spectroscopy in the NIR (system II) to successfully examine drawings: Although being undistinguishable for the human eye, this approach allowed to differentiate between various drawing materials [2,3]. A careful re-evaluation of more than 1.600 reflectance spectra, a first use of multivariate statistics and a first application of image processing techniques to drawings [4] encouraged us to combine the two systems, I - the imaging technique - and II - the spectroscopic approach - as well as to widen the wavelength range from about 300 to 2.000 nm. Due to limited space we shall restrict this contribution to one single application, i.e. to the investigation of drawings in the range of 400 to 1.800 nm.

EXPERIMENTAL SET-UP

Our experimental set-up consists of a lighting unit, a monochromator, a camera with optics, additional filters, a repositioning unit and a workstation.

Lighting

For lighting we use a 250 W halogen lamp unit in the VIS and the NIR. To select the wavelength range required a monochromator is used. For conservation reasons we recommend to filter the light on its way to the object. In contrary to a set-up with interference or narrow band filters (in most cases in front of the camera) [5] the monochromator is freely tunable over the wavelength range mentioned with a FWHM between 40 and 80 nm. All the images offer a specific wavelength related information.

The choice of a monochromator has some disadvantages. (1) The illuminated area of about 10 by 10 cm is rather small. (2) Because of chromatic aberrations of the optics or diffraction on the monochromator grid the area is illuminated with light of slightly different wavelengths. This is uncorrectable, whereas (3) an observed unevenness of the illuminance (caused by the lamp itself) can be corrected to some extent. (4) Finally, higher order overtone radiation has to be filtered out properly.

Camera and Filtering

In the case of the application to drawings all images are taken with a HAMAMATSU vidicon camera C2400-03-DSC with N2606-06 tube sensitive in the VIS and NIR. We described the low long-term stability of the HAMAMATSU camera, its resolution lower than specified, its low dynamic range and other disadvantages earlier [1]. A fan is now used to stabilize the cameras long-term temperature behaviour. To improve the signal-to-noise ratio between 16 to 64 frames are averaged. After digitization, the resulting float images are used to increase the low dynamic of 6.5 bit (referring to integer number images) to about 8.5 bit.

During our recent experiments, filtering was set up to suit individual conditions with the main aims (1) to block out the higher order overtone radiation mentioned, (2) to keep the light level on a reasonable level and, thereby, to protect the object as well as (3) to exclude fluorescence radiation. Typically, one filter is placed between the light source and the monochromator to protect the latter. Depending on practical considerations (mainly filter size), a second filter is either located behind the monochromator or in front of the camera.

Positioning Unit

As mentioned, the area imaged is about 10 by 10 cm. However, most of the objects under examination are larger than this. Therefore, the whole experimental set-up is systematically moved parallel to the work of art on a 3d-positioning unit described elsewhere [6].

Computing and Acquisition

Most of the components are controlled from a SUN SparcStation 2 with an UNIX operating system: A shell-script and a couple of linked C-routines control the positioning unit. They allow the wavelength of the monochromator to be selected in steps, to control the frame grabber and the A/D converter, to handle the resulting images and to store them to disc. After A/D conversion all single subframes have a size of 768 x 575 pixels. Depending on the resolution selected (which is usually 3 to 5 lines/mm on the object) and the total size of the art object, up to *n* subimages horizontally and *m* vertically have to be taken from the object. In a second step, a white or grey card board mounted beside the object is grabbed to determine the lighting distribution. One additional image with closed lens is grabbed to control the dark current. To quantify the analogue signal of the camera, calibrated white and black reflectance standards are finally imaged.

EVALUATION

Following a complex algorithm [7], the described set of raw images is used to calculate the relative reflection coefficients. The coefficients are corrected against the spectral sensitivity and off sets of the camera and the A/D converter, inhomogeneities of the illumination and calibrated against the standards. This is done for each of the pixels resulting in a data cube consisting of $(n \times 768) \times (m \times 575) \times 29$ data points. Appropriate software enables us to either extract the spectra of a distinct area or to represent the object at a distinct wavelength. In the latter case, resampling and mosaicing procedures are used to produce a complete presentation of the object from the $n \times m$ subimages [8].

As a third and pioneering step, the data cube is evaluated with advanced statistical procedures [9,10]. The main reason to do this, is to help with the interpretation of the 57 MB of data:
(1) In a first step, a factor analysis (principal factor analysis) is used to compress the data. In the case of reflection spectra this is successful, because the spectra with their broad peaks are highly redundant. In our experience, the data

cube can be compressed by a factor of ten without significant loss of Information.

(2) The resulting factor space is then rotated to get a clearer presentation. The factor loadings help to identify relevant wavelength ranges.

(3) Moreover, the factor loadings serve to create, as we call it, factor images. These can be handled as common images. They show the spatial distribution of the ink strokes on the drawing as we are used too, but reveal the hidden information contained in the data cube.

(4) As we know from previous work, some drawing materials differ in their reflectance behaviour. The compressed and rotated data from (2) undergoes a second factor analysis (principal component analysis) to produce the final representation of the object. This resulting factor image is composed of various grey values each representing different (drawing) materials.

APPLICATION

Up to now, our system has been used for the investigation of pigments, minerals and drawings. Following a presentation given at Berlin some years ago [11], this contribution will focus on the well-known 'Rembrandt-Fakes', or better 'Rembrandt-Apocryphs'. The apocryphs, roughly 400 in all, have a changeable history: Once attributed to Rembrandt, then told to be simple fakes they are now seen to be drawn by different artists and later altered always in the same typical way [3]. In a few cases, a slightly different colour in the inks of the alterations allowed us to identify the original part and later additions including all 'Rembrandt'-signatures. First spectroscopic examinations in the VIS and NIR by one of us (A.B.) gave a fragmentary understanding of the situation [2]. Our experiments indicated that imaging spectroscopy would give a full understanding of the distribution of different inks [4].

We recently re-examined ten of the drawings with the system described above. Each of the drawings had been imaged with up to four (n=2 and m=2) subimages at 29 wavelengths with a step width of 50 nm in the range of 400 to 1.800 nm. The most interesting drawing has been selected for this contribution. On this drawing (Figure 1) with its typical reflectance spectra as extracted from the data cube (Figure 2), the existence of different drawing inks had not been reported ever. However, the existence of three different inks has to be seriously considered [12]. In a first step, the data cube of 57 MB is subjected to a factor analysis. Its first three rotated factors [13] are shown in Figure 3. The most relevant range (Factor 1) is between 850 and 1.400. A second between 400 and 800 (Factor 2) with a maximum at 550 nm [14]. Finally, the third range is between 1.500 and 1.700. The following factors allow the Interpretation to be linked to the manual refocussing at 1.050, 1.350 and 1.650 nm, to the decrease in sensitivity in the VIS and NIR and to a change of the monochromator grid at 850 nm.

By multiplying the factor loadings of a distinct Eigenvector with the related subimages (reflectance at a distinct wavelength band) factor images (FIs) can be built. The first three FIs are shown in Figure 4 to 6. As is to be expected from Figure 5, the second FI is more or less identical with the 'visible' information (see Figure 1). The two others allow us to differentiate at least between two drawing materials, as can be seen from the grey values. However, the third FI (Figure 6) shows a lot of noise and most of its information is included in the first FI (Figure 4). Therefore, it is to be expected that most of the information to differentiate between the drawing materials involved will be found in the first and second FI.

We succeeded in differentiating all the materials used on the drawing in a best possible way. This is visualized in one single FI which is identical to a projection in a subspace with highest possible separation. A second factor analysis on the base of the first three previous rotated factors yield this presentation (Figure 7). Here, three drawings materials and the paper can be identified in an optimal way. The result fits perfectly with the art historian's understanding of this drawing and underlines the Interpretation and hypothesis published by one of us (A.B.) and his co-author [3].

DISCUSSION

This contribution aimed to demonstrate the general usefulness of remote imaging spectroscopy for the non-destructive investigation of drawings. Whereas previous work proved the feasibility of an application of reflectance spectroscopy or Imaging techniques to drawings, we now succeeded in combining these two approaches. The application of a factor analysis to evaluate the generated reflectance data cube leads to a general solution: This allows to differentiate materials by using their reflectance behaviour without sampling or touching the object. We believe, that our approach will find other applications in the future.

ACKNOWLEDGEMENTS

This work has been conducted in the context of the MUßINI project which has been funded by the Bundesministerium für Forschung und Technologie (03-BU9MUE). The authors are responsible for the content of this contribution. Our application has only been made possible by the generous loan of a number of the Rembrandt-apocryphs by the Staatliche Graphische Sammlung, München (Dr. Thea Vignau).

CAPTIONS

Figure 1	"Woman and Child between Two Other Women in Profile toward the Right" (W. 762, Staatliche Graphische Sammlung München), here at 600 nm
Figure 2	As Figure 1, set of characteristic reflectance spectra
Figure 3	As Figure 1, factor loadings
Figure 4	As Figure 1, factor image 1
Figure 5	As Figure 1, factor image 2
Figure 6	As Figure 1, factor image 3
Figure 7	As Figure 1, final factor image after the second factor analysis. Observe the excellent separation of the three inks used.

BIBLIOGRAPHY AND REMARKS

1 A. Burmester und F. Bayerer, Towards Improved Infrared-Reflectograms, Studies in Conservation 38 (1993), 145-154.

2 A. Burmester, K. Renger, 'Neue Ansätze zur technischen Erforschung von Handzeichnungen: Untersuchungen der Münchner Rembrandt-Fälschungen im Nahen Infrarot', *Maltechnik Restauro* 92 (1986), 9-34

3 K. Renger, A. Burmester, 'The Munich Rembrandt Forgeries Reconsidered. A New Technical Approach to the Investigation of Drawings', *Master Drawings* 23/24 (1985/86), 526-537.

4 A. Burmester, The Study of Drawings in the Near Infrared, in: Proceedings of the 12th International Symposium on the Conservation and Restoration of Cultural Property, Analysis and Examination of an Art Object by Imaging Technique, Tokyo National Research Institute of Cultural Properties 1991, 61-82.

5 M. Bacci, S. Baronti, A. Casini, F. Lotti, F. Meiners and O. Casazza, Near Infrared Narrow Band Imaging of Paintings, Poster presented at the 3rd International Conference on Non Destructive Testing, Microanalytical Methods and Environmental Evaluation for Study and Conservation of Works of Art (Viterbo 1992).

6 A. Burmester, J. Cupitt, H. Derrien, N. Dessipris, A. Hamber, K. Martinez, M. Müller und D. Saunders, The Examination of Paintings by Digital Image Analysis, 3rd International Conference on Non Destructive Testing, Microanalytical Methods and Environmental Evaluation for Study and Conservation of Works of Art (1992), 201-214.

7 Unpublished Thesis F. Bayerer, University of Ulm, Spring 1995.

8 For some of the image processing we used the VIPS 7.2 software package, developed under the VASARI and MARC project (ESPRIT no. 2649 and 6937) by the National Gallery London and Birkbeck College London.

9 For some statistical calculations the software package Intercooled Stata 3.1, Stata Corp., has been used.

10 K. Backhaus, B. Erichson, W. Plinke, Chr. Schuchard-Ficher, R. Weiber, Multivariate Analysenmethoden, Berlin 1986^4.

11 A. Burmester, Remissionsspektroskopie und Infrarotreflektographie an Handzeichnungen, Paper given at the Symposium Zerstörungsfreie Prüfung von Kunstwerken, Berlin 1987.

12 see [3] p. 532.

13 In this case, a non-orthogonal rotation of the factors has been applied.

14 In the case of other drawings, some scholars insisted on seeing two or even more different media. This could be explained by the varying ability of the human eye to see in the area above 750 nm. In this case, the low loadings between 800 and 1.050 nm may explain why nobody ever could distinguish different drawing media by eye.

Figure 1

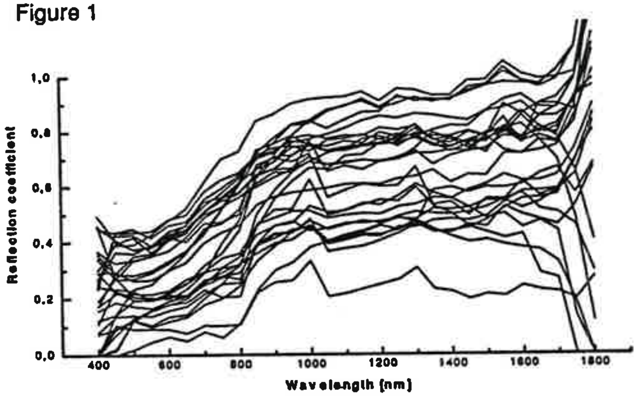


Figure 2

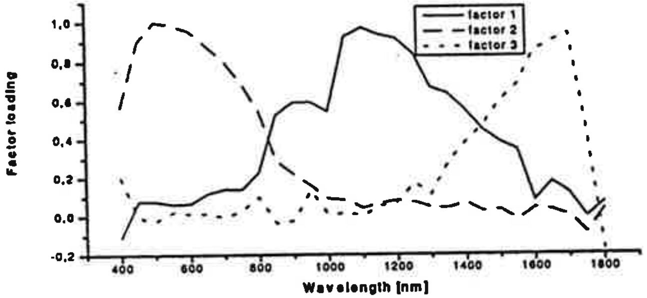


Figure 3

Figure 4

Figure 5

Figure 6

Figure 7