International Symposium on the Conservation and Restoration of Cultural Property
- Spectrometric Examination in Conservation -

Nondestructive Imaging Spectroscopy of Drawings and Paintings

Florian BAYERER

Tokyo National Research Institute of Cultural Properties

1996

NONDESTRUCTIVE IMAGING SPECTROSCOPY OF DRAWINGS AND PAINTINGS

F. BAYERER and A. BURMESTER

SUMMARY

An imaging spectroscopy system has been developed which allows the imaging of objects of art at different wavelength ranges between 250 and 2000 nm with high spatial resolution. The spectral information acquired is evaluated by appropriate multivariate statistics. The system has been successfully applied to the investigation of drawings (Munich Rembrandt-Apocrypha) and artists' pigments (titanium white).

INTRODUCTION

A growing number of analytical methods are currently available for obtaining information concerning the nature of the materials used in art objects. Most of these methods require taking an actual sample from the object. In addition, the results only allow a statement concerning the limited area of the object from which the sample was taken. The importance of non-destructive investigation methods has thus increased recently. These methods can be divided into two groups: those where single spot measurements are carried out and those which allow the imaging of the entire object. In the latter case, the resulting observations can be correlated with the shape of the objects or the distribution of the materials on the object. In the area of drawings and paintings, traditional imaging techniques such as UV (ultraviolet) - fluorescence photography or infrared reflectography are applied. In most cases, a set of edge or interference filters is used to select the appropriate wavelength range. This approach can be refined by using spectroscopic methods which usually only allow spot measurements.

In a previous publication it was demonstrated by one of the authors (A.B.), that for many difficult applications, a combination of both approaches, the spectroscopic approach as well as the imaging approach, yield valuable information which could not be otherwise obtained with only one method[1]. It was suggested that the problem of the set of Munich Rembrandt-Apocrypha[2] drawings can only be solved with this combination of the two approaches, known as imaging spectroscopy. The research project MUβINI (Bundesministerium für Forschung und Technologie 03-BU9MUE) was initiated to develop a system for imaging spectroscopy. This contribution briefly discusses the experimental set-up and presents recent applications demonstrating the usefulness of such a system for the non-destructive investigation of drawings and paintings.

EXPERIMENTAL SET-UP AND EVALUATION PROCEDURES

Technical details of the system have been presented recently and are only briefly summarized here[3,4]. The system consists of a lighting unit including a monochromator, two cameras with optics, filters, a positioning unit, a UNIX work-station and a complex software package. The system was designed to investigate works of art within the range of about 250 to 2000 nm as defined by the choice of cameras. A 150 W Xe (UV) or a 250 W halogen lamp (VIS - visual, NIR - near infrared) is used for lighting. The monochromator selects wavelength bands of 40 nm for UV, VIS or 80 nm for NIR. The use of a monochromator as opposed to a set of filters (as proposed by others) is based on the advantage of flexibility. However the uneven illumination of the object is still an open problem. A COHU 4912-5000 monochrome CCD camera (UV, VIS) and a HAMAMATSU vidicon camera C2400-03-DSC with a N2606-06 tube (VIS, NIR) are used as spatially resolving sensors. By replacing the glass plate in front of the CCD sensor by a quartz plate and by using a quartz lens (UV-Achromat OUV 1.4.13, f = 50 mm), the COHU camera has been made sensitive down to below 250 nm.

The acquisition process is described elsewhere[3]. The following comments can be made to this procedure:

(1) The brightness and surface roughness of the white or grey cardboard which is used to compensate illumination inhomogeneities should be comparable to the object.

(2) The dark current of the HAMAMATSU camera is very unstable due to the low long-term temperature stability of the camera. The dark current therefore has to be monitored for each wavelength. This effect is much lower for the COHU CCD camera.

(3) To quantify the analogue signal of the cameras, calibrated white and black reflectance standards (Labsphere) are imaged. Depending on the objects, these standards are imaged together with or separately from the object.

(4) The illuminated area of the object is only 10 by 10 cm. Most objects are usually larger than this. This, combined with the low resolution of both cameras (e.g. for the COHU 752 (H) x 582 (V) pixels) requires the use of a positioning unit (the VASARI system[5]) to move the camera including all other optical components. In each position and for each wavelength band a sub-image is acquired. After conversion into reflectance values, a data cube is obtained which includes the spatially resolving as well as the wavelength dependant information (imaging spectroscopy).

Experience to date has shown that the handling and interpretation of the huge data cube is difficult. As proposed previously[1], multivariate statistical data analyses for data compression and improved presentation is used. For all applications, data compression is performed whereby all data points (e.g. ink and paper in the case of drawings) at n wavelengths are included. A principal component analysis is used to transform the spectral information in a way which allows the reduction of the data cube to far less than n dimensions. In practice, this step is often replaced by a principal factor analysis, which differs only slightly from a principal component analysis, but facilitates further data treatment (usually a rotation of the resulting space). After compression, experience has shown that the pure spectral information is to be found in the first dimensions followed by experimental information (e.g. defocussing caused by the dispersion of the lenses used) and then noise. After appropriate weighting, the first three dimensions are loaded into the RGB (red-green-blue) channels of a colour image. This image reflects most of the spectral information of the chosen range in one image, which may include ranges not visible to the human eye. Further data processing depends on the application and is described in the following section. The usefulness of our approach is now demonstrated with some applications.

APPLICATIONS

A number of investigations were conducted using the imaging spectroscopy system during its development. Full data cubes were acquired of ten of the drawings from the Munich Rembrandt-Apocrypha[1,2,6] and of artists' pigment charts. In the former case, a general solution to the problem described below was found which can be applied to similar problems. In the latter case, initial results are reported.The purpose of the investigation of the Munich Rembrandt-Apocrypha drawings was to separate the different inks of the original drawing and later additions including faked Rembrandt signatures.

As an example, the results of the work on the drawing "Christus segnet die

Kinder" (Staatliche Graphische Sammlung München, W747) are presented. This drawing has been described in a previous publication as a difficult case[2]. The data cube acquired consisted of two sub-images at 29 different wavelengths in the range between 400 and 1800 nm. As for all other Munich Rembrandt-Apocrypha, the data compression was slightly modified to include the following initial data interpretation: (1) exclusion of all paper points due to their redundancy and (2) a principal factor analysis instead of the principal component analysis. The use of a principal factor analysis allows a non-orthogonal rotation afterwards. The resulting rotated factor loading plots, i.e. plots of the weighted wavelengths, and factor images, i.e. sum of the products of factor loadings by related reflectance coefficients, provided valuable information.

The results of this study are shown in Figures 1-3. Figure 1 shows the factor loadings for factors 1 to 3. Figures 2a to c show the three factor images. According to the factor loadings in Figure 1, Figure 2a shows the drawing in the range of about 1100 to 1800 nm. Only a few ink strokes which relate to the border, the zig-zag-lines, the signature, and the paper joint are visible whereas most of the composition itself remains invisible. Figure 2b bears the information in the range from 600 to 1100 nm. Here, in addition to the composition itself, the red-brownish wash is most visible. Figure 2c reflects the lower part of the VIS from 400 to 600 nm and reproduces the drawing without the ink-wash.

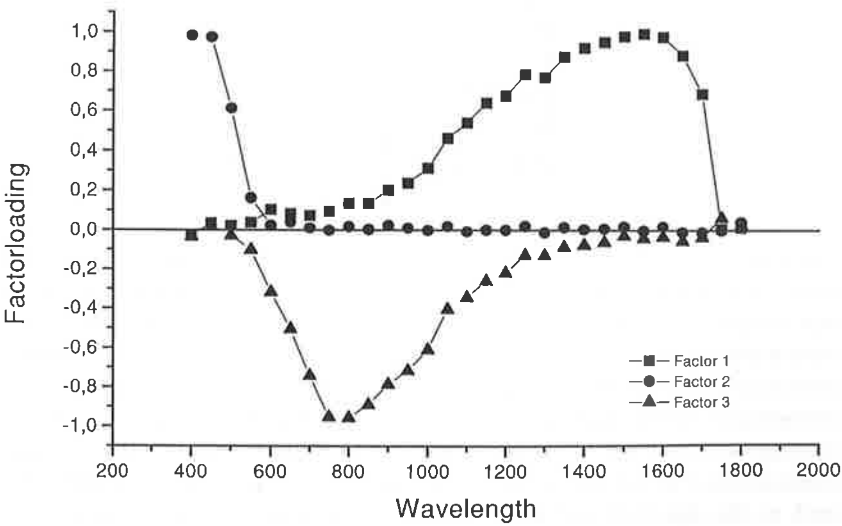

Figure 1

Figure 2

Figure 3

It appears that three different inks were used on the drawing. To visualise their 'material contrast' optically, a differentiation by means of grey values on one single computer image was performed. Irrelevant or redundant information above factor 3 was discarded. As a final step, a principal component analysis (orthogonal) was performed to find an optimal presentation of the material contrast. Figure 3 shows the highest material contrast between the three inks used on the drawing, one for the original composition, one for the original wash and the other for the later additions such as the signature and ink strokes along the joint. A collector stamp and the shadow in the left corner (the drawing had been illuminated from the right) do not principally affect this result, but slightly diminish the quality of the presentation.

In summary, the results of the analyses of this drawing shows (1) a border, zig-zag lines and a (faked) signature in the lower right-hand corner, all of them being typical for many of these Apocrypha. Because of a change in the composition of the drawing, (2) a piece of paper was inserted in the lower left quarter. The joint between the two pieces of paper has been drawn over by heavy ink strokes. Additionally, (3) the background has been ink-washed and (4) a collector stamp has been placed in the lower left corner. (These observations are not listed in the order of their creation.) Two final remarks should be made: The situation on "Christus segnet die Kinder" is far more complex than in the case of another drawing discussed recently[3] and single spot reflectance spectroscopy[6] gave no clear answer as to whether and how many types of ink had been used.

The second application deals with the identification of artists' pigments. Currently, all such work is conducted by destructive microanalytical techniques. It is therefore of great interest to determine whether or not the identification of pigments by non-destructive techniques is feasible, fast and reliable. Some of the earlier attempts by other researchers to reach this goal by means of imaging techniques have been restricted to the VIS[7,8]. Recent

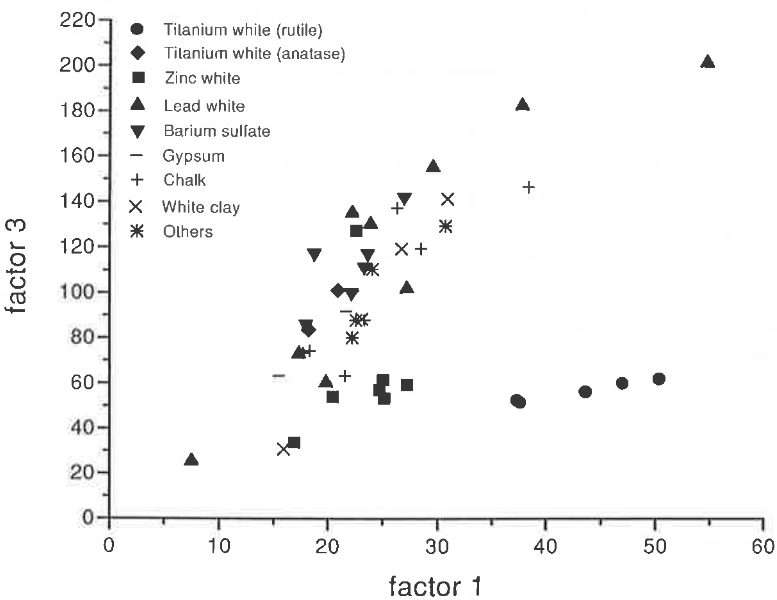

Figure 4

applications expand this range towards the NIR[9,10,11]. The system presented above additionally includes UV and the capability for the appropriate statistical evaluation of the data. The experiments conducted thus far have yielded interesting results. An example is work conducted to determine the feasibility of identifying titanium white. The relevant data cube includes the wavelengths at 350, 375, 400, 425, and 450. The result of a factor analysis is shown in Figure 4 (also See Color Plates). The plot of factor 1 against factor 3 shows a clear separation of titanium white (rutile) from all other whites. These include, however, titanium white (anatase). The other whites can not as yet be differentiated by imaging spectroscopy. It is intended to use these observations to survey 20th century paintings in order to study the history of the use of titanium white (rutile).

DISCUSSION

It has been shown that the combination of imaging spectroscopy in the VIS and NIR and of multivariate statistical methods yields a satisfying representation of the use of different inks for drawings and pigments for paintings. The system for imaging spectroscopy developed during the MUβINI project has enabled the problem of the Munich Rembrandt-Apocrypha, disputed since the beginning of the century, to be finally solved. Only the combination of this acquisition system with multivariate statistics has allowed the compression of the huge amounts of data collected during the imaging experiment, and the elucidation of the relationship between distinct drawing materials and wavelength ranges. The spectroscopic approach widens at the same time the range which can be covered by the eye of the observer, i.e. it includes the UV and the NIR. Furthermore, these techniques allow the presentation of the results in a way which can be used directly by art historians. This now allows them to safely differentiate between the original drawing and later alterations, and opens new possibilities to determine the origins of drawings.

The application of this system to artists pigments is in its beginnings. It appears, however, that imaging spectroscopy may serve as a useful tool at least for the fast and non-destructive identification of titanium white (rutile).

ACKNOWLEDGEMENTS

This work was conducted under the MUβINI project which is funded by the

Bundesministerium für Forschung und Technologie (03-BU9MUE). A generous grant has been given to one of us (F.B.) by the Bundesministerium für Forschung und Technologie (215 - 3789 - GKS 1300 3) and by the Japanese government. Our first application was only made possible by the loan of a number of the Rembrandt-Apocrypha by the Staatliche Graphische Sammlung, Munchen (Dr. Thea Vignau). Finally, we would like to thank Prof. Dr. D. M. Kolb (Universitat Ulm) for his support and advice, as well as Dr. W. Wei for reviewing this manuscript and Ms. Carola Komar for creatively painting pigment charts.

References

1) A. Burmester: "The Study of Drawings in the Near Infrared", 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, (Tokyo,1991), 61-82.

2) 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.

3) A. Burmester und F. Bayerer: "Remote Imaging Spectroscopy of Drawings", Proceedings of the 4th International Congress on Non-Destructive Testing of Artistic and Cultural Objects, (Berlin 1994), in print.

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

5) 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.

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

7) N. F. Barnes: "A Spectroscopic Study of Artists' Pigments", *Technical Studies in the Field of Fine Arts,* **7**, 120-138 (1939).

8) M. Bacci, F. Baldini, R. Carlà and R. Linari: "A Color Analysis if the Brancacci Chapel Frescoes", *Applied Spectroscopy,* **45**, No. 1, 26-31(1991).

9) A. Aldrovandi, D. Bertani, M. Cetica, M. Matteini, A. Moles, P. Poggi and P. Tiano: "Multispectral Image Processing of Paintings", *Studies in Conservation,* **33**, 154-

159(1988).

10) C. Hoeniger: "The Identification of Blue Pigments in Early Sienese Paintings by Color Infrared Photography", *JAIC*, **30**, 115-124(1991) .

11) M. Bacci, S. Baronti, A. Casini, F. Lotti, M. Picollo and O. Casazza: "Non-Destructive Investigations on Paintings Using Optical Fibers", *Mat. Res. Soc. Symp. Proc.*, **267**, 265-283(1992).

F. Bayerer and A. Burmester

Doerner-Institut, Bayerische
Staatsgemäldesammlungen
Barer Str. 29, D-80799
München, Germany

DISCUSSION

Kharbade: You used different color to indicate pigments. They are not real colors, are they?

Bayerer: No, they are not.

Kharbade: You have studied pure pigments. Have you studied samples in which two different pigments were mixed? Were you able to distinguish those pigments? For example, where there are different crystals with the same chemical composition, like gypsum, is it possible to distinguish them?

Bayerer: Until now, I have not studied composites of different white pigments. I think it is very difficult to distinguish with this method.

Segebade: Can you apply this method to three-dimensional objects like polychromed sculptures?

Bayerer: I think the problem would be that it would be difficult to set the focus when the object is three-dimensional.

Segebade:Is there no risk that the lighting that is used for this method might damage the object?

Bayerer: I don't think so. In this method, we selected the range of wavelength to make sure that the object is exposed to light of very low energy.