Journal of Optoelectronics and Advanced Materials Vol. 7, No. 2, April 2005, p. 1107 - 1111

Technical note

OPTOSPECTRAL SYSTEM FOR THE QUANTIFICATION OF OPTICAL PARAMETERS OF OLD PAPER

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A specialised spectral multichannel device was built in the view of characterisation of paper manuscripts (codices). It is based on a spectrophotometric module with a concave diffraction grating and a CCD detector. The tests on the manuscripts were performed by measuring the reflectance in a $45/0^o$ geometry. The measured spectral data were used for the calculation of the color parameters in the CIELAB space. The device was tested for applications in conservation-restoration at the National Centre for Conservation and Restoration of Historical Publications within The National Union Museum from Alba Iulia (Romania) by using a Romanian manuscript dating from the 18th century.

(Received March 14, 2005; accepted March 23, 2005)

Keywords: Optospectral system, Spectral reflectance, Old paper

1. Introduction

During the restoration-conservation work of paper manuscripts, the assessment of the state of art of the manuscript before, and after the procedure, as well as at regular intervals plays a special importance. Currently these evaluations are based on visual inspection and the brief information is registered in a conservation file. The detailed description of the state of the object before and after restoration is included in the extended restoration folder, which includes a wide range of information on the conservation status, such as the types of interventions and the materials used during the restoration process [1]. For an objective characterisation of the manuscripts, an instrumental method is needed, that provides reproducible measurements of the quality of the paper ground.

The proposed method is based on the measurement of the spectral reflectance by using the $45/0^o$ geometry, in the spectral range 380...900 nm [2]. The characterisation of the paper ground is based on the reflectance spectra. The spectral changes may be traced by using the color parameters in the CIE 1976 L*a*b* color space (CIELAB) [3, 4].

2. Description of the proposed device "Optospectral system for the quantification of optical parameters of old paper"

The optospectral parameters may be used for the identification and source-evaluation of art objects on paper ground due to the fact that the methods are non-destructive, using the light reflection and transmission. Based on these considerations a complex device has been created, defined as an "*Optospectral system for the quantification of optical parameters of old paper*", that can be used for the characterisation of several parameters of the paper ground under consideration: assessment of the natural or artificial ageing, of the impact of the environment or microbiologic

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activity, and selection of the most suitable materials to be used for conservation and restoration. The apparatus uses non-destructive optical methods based on reflectance spectrometry, *i.e.* the investigation of the spectral composition of an optical radiation reflected by a surface. The spectrophotometric module uses a concave diffraction grating and a CCD detector. The opto-spectral parameters of significance for the research on historical paper, that can be determined by using this equipment, are: • spectral reflectance • transmittance (opacity) • whiteness degree • yellowness degree • legibility • color parameters (L*,a*,b* coordinates in the CIELAB color space, hue and chroma) • color differences.

The CIE 1976 L*a*b* color space (CIELAB) is the most widely used method for measuring and ordering object color. It is routinely employed throughout the world by those controlling the color of paper, printed materials, textiles, inks, paints, plastics and other objects. In the CIE L*a*b* uniform color space, the color coordinates are:

L* - the lightness coordinate.

a* - the red/green coordinate, with +a* indicating red, and -a* indicating green.

b* - the yellow/blue coordinate, with +b* indicating yellow, and -b* indicating blue.

C* and h* coordinates are computed from the a* and b* coordinates: C* - the chroma coordinate, the perpendicular distance from the lightness axis (more distance being more chroma), h* - the hue angle, expressed in degrees, with 0° being a location on the +a* axis, then continuing to 90° for the +b* axis, 180° for -a*, 270° for -b*, and back to 360° = 0°.

The needed experimental conditions do not influence the paper's quality. The method of investigation may be used regardless of the shape and size of the object (manuscript), or of the type of paper ground. The measurements are however influenced by the current conditions of illumination and viewing area. The optical geometry of the proposed device takes into account the recommendations of the International Commission for Illumination (CIE) – geometry: 45/0°, observer: 10° (CIE 1964), illuminant: C.

3. Description of the manuscript under study

The research has been performed on the paper ground of a Romanian manuscript edited in the 18th century. The *in folio* volume has 471 leaves grouped into folders. The ground of the manuscript is represented by a manually-produced paper consisting of flax and hemp glued together with gelatine. The paper ground shows the following features: • good quality • it is traced with water lines and vertical filigree • it does not show defibrillated particles within the groundmass • it shows a slight nebulosity along the water lines trajectory. The writing has been done on a single column by using ferro-galic ink. The manuscript shows an original bound and it was tied with strings along three profiled ribs. The edge is rounded, the wreath (headband) is knitted on string core, with a simple festoon. The bindings are made of hard wood with covers of leather tanned with vegetal tannins.

The paper ground in the first part of the manuscript is highly degraded along the writing traces, due to the effect of the used ferro-galic ink – that was incorrectly prepared, and due to the relatively high humidity of the environment where the manuscript was kept. As a result, the paper ground was highly acidified at the contact with the ink, thus leading to strong local blackening and fragility. In consequence the written information was lost in many parts. It can be noticed that the marginal parts of the pages, where writing is missing do not show major degrading of the paper ground. The following leaves of the manuscript show a relatively good conservation state, still slight brownish hues may be noticed along the writing traces. In the last part of the manuscript the acid degradation related to the writing traces is not visible anymore, as a result of the subsequent dilution of the ink performed by the scribe.

4. Experimental results

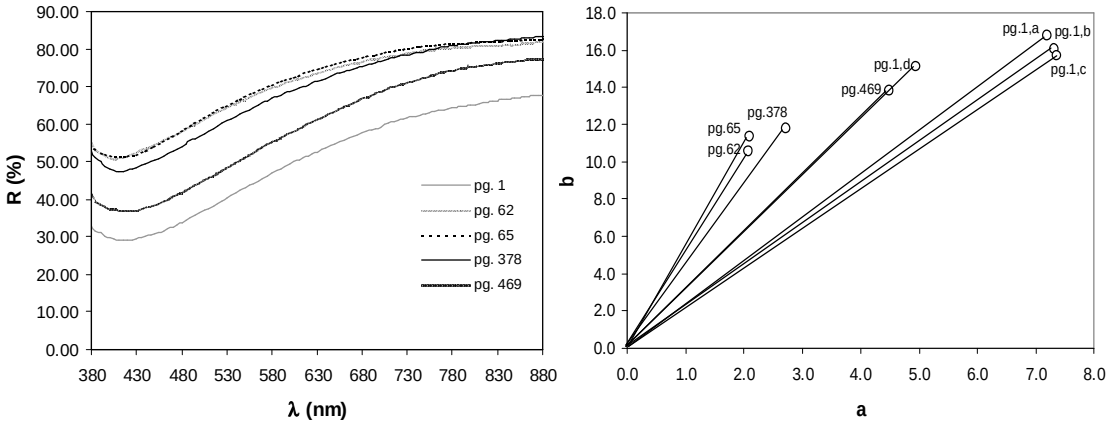
The **"***Optospectral system for the quantification of optical parameters of old paper*" was used for performing a set of measurements along the writing traces on different pages, as well as

from various areas of the same page on the paper ground of a manuscript from the 18th century. The pages submitted to the data collecting will be briefly described below – the thickness of the paper was measured with the electronic micrometer:

- *Leaf 1:* paper thickness is 0.15 mm; the sheet presents circular and branched channels made by wood eating insects, at the contact with the wood bindings. The color of the paper was changed due to the effect of light. Measurements have been performed in four different spots (pg. 1a, pg. 1b, pg. 1c, pg. 1d); the leaves at the extremities of the manuscript show similar features.
- *Leaf 62*: paper thickness ranges between 0.14-0.16 mm; the conservation degree is relatively good; the paper ground was not altered along the writing traces due to the ink. No signs of bacteria or fungi attack were recorded. The original color of the ground was only affected by the surface dust and that penetrating the space in-between the cellulose fibres.
- *Leaf 65:* paper thickness ranges between 0.14 – 0.15 mm; it is highly similar to leaf 62, including the hue and luminosity.
- *Leaf 378:* thickness 0.19 mm; the paper ground is covered by relatively more adherent dust. Luminosity decreased – the paper is more yellowish, and also the hue is modified. It presents a good conservation status. As compared to the other investigated leaves, leaf 378 is significantly thicker; for the thinner leaves it can be generally noticed that the ink – when diluted, penetrates also the opposite side of the sheet and becomes noticeable.
- *Leaf 469:* thickness 0.15 mm; wood eating insects attacked and perforated the sheet. Due to the effects of light, the color was modified. The luminosity and the hue decrease, as opposed to the increase of the saturation (Fig. 1).

Based on the measured spectral values, the lightness (L), the chroma (C) and hue (h) were calculated and plotted in the CIELAB space – Fig. 1.

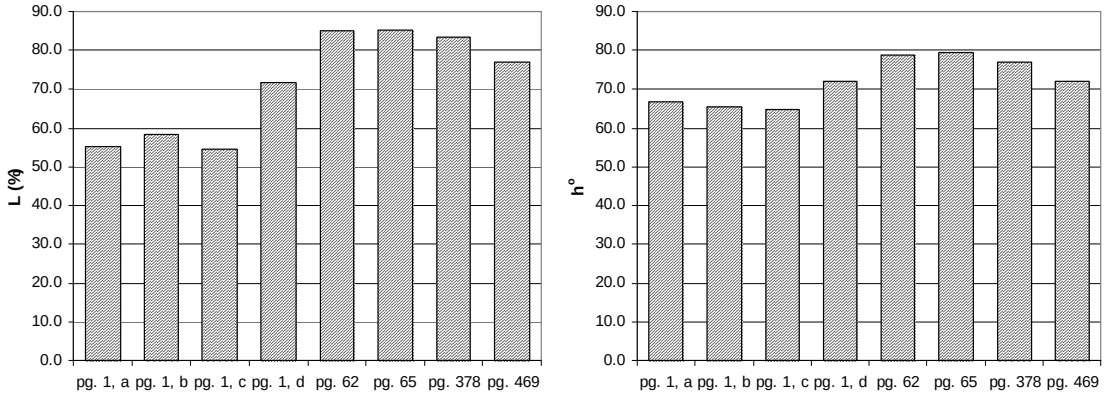
The reflectance spectra (Fig. 1a) are very similar, with differences characterising the first (1) and the last (469) leaves. When plotting the data in the CIELAB space (Fig. 1b), it can be noticed that all the measurements are located in the first quadrant (positive a and b). The different areas measured within the same page (leaf 1) plot very similarly (pg. 1 - a, b, c) except for spot pg. 1d, that corresponds to a more degraded area.



a) b)

Fig. 1. a) Reflectance spectra b) Plot of the measured spots in the CIELAB colour space.

It is worth to mention that according to the location of the leaf within the manuscript, both chroma and hue are modified (Fig. 2). They vary in a similar trend in all the measured areas. At the beginning and the end of the manuscript the pages are darker (reduced lightness) and show a yellowish shade (yellow: $h=90^o$) richer in red shade (red: $h=0^o$).



a) b)

Fig. 2. Lightness a), and hue of the measured areas b).

Chroma decreases in the case of the leaves located in the middle part of the manuscript (Fig. 3a). These sheets were less degraded and submitted to colour changes being more protected from light and other destructive factors.

By taking one of the very-well preserved sheets as a reference (leaf 62), the color differences for the data measured from other leaves can be calculated (Fig. 3b). Changes of the color differences can be noticed between the studied areas. The large color differences indicate a poor conservation status and the degrading of the respective areas.

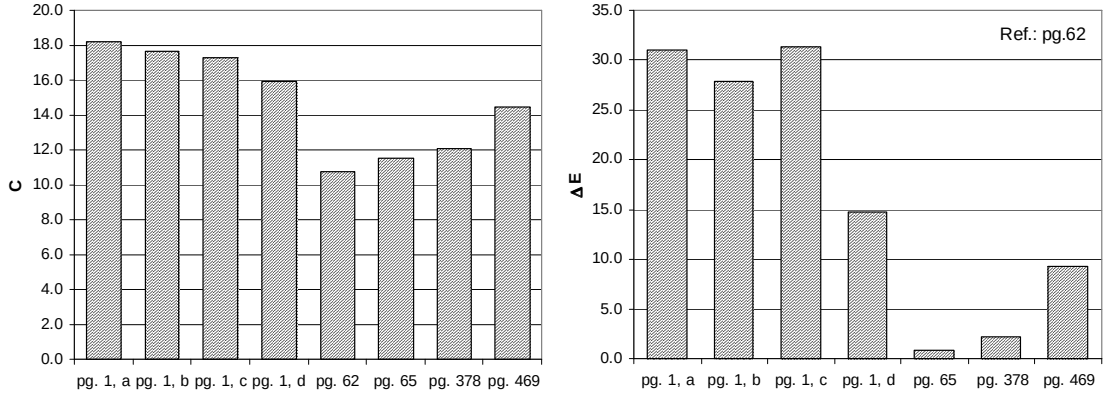


Fig. 3 a). Saturation of the measured areas. b) Colour differences calculated as compared to leaf 62.

The thickness of the paper ground is a very important factor that has to be taken into account for a correct restoration of the old manuscripts edited on manual paper. According to this feature, several observations have been recorded: • the thin paper is more degradable • during the restoration procedure, the thickness differences occuring on the same sheet may cause problems which have to be solved by the expert by choosing a suitable type of additional paper for each specific area • the constant thickness of the paper sheet is an indicator for its quality – if it was produced by a well-known craftsman by using an acknowledged paper mill • the thinner paper had been considered a low quality product, thus being cheaper.

In the case of the studied manuscript, the penetration of the ink on the opposite side of the sheets is mainly due to the dilution of the ink, the paper ground being not specifically thin, thus cheap. The relative constant thickness of the investigated sheets, except for leaf 378, points to the usage of a high quality paper produced by using an acknowledged paper mill. Due to the relative

higher thickness of the paper in leaf 378, the ink is not so visible on the opposite side of the sheet. Based on the presence of the water lines and the filigree, one can state that the paper originated from a single paper mill, but it belonged to different production lots.

5. Conclusions

The specific spectral multichannel device built for this application is based on a spectrophotometric module with a concave diffraction grating and a CCD detector. The apparatus can be successfully utilised for the characterisation of the paper ground manuscripts.

The testing of the manuscripts was performed by reflectance measurements in $45/0^{o}$ geometry. Based on the obtained spectral data the reflectance spectra have been plotted and the color parameters in the CIE 1976 L*a*b* color space (CIELAB) have been calculated. The results evidence the differences related to the conservation status and the degree of deterioration of the various areas on the leaves of the document under study.

The device can be used in expert laboratories for spectral parameters investigations applied also to other solid objects delimited by plane surfaces.

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