Article

The Evolution of Imaging Techniques in the Study of Manuscripts

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1. Introduction

This paper outlines the evolution of non-destructive testing in the study of manuscripts. This overview starts with the time when manual SLR cameras, photographic films and huge infrared analogue tubes were the cutting edge. It arrives at current practice, in which extremely high-resolution DSLR cameras and other digital camera systems coupled with hyper-spectral imaging approaches are used for acquiring image sequences in different spectral regions. The term 'non-destructive' refers to those techniques – mainly imaging – that provide information without invasive activities, as opposed to chemical analysis, which requires sampling the object.

Moreover, modern technology enables the collection and distribution of large volumes of information that can now be analysed intuitively and quickly and assessed with the help of continuously developing and improving IT systems and software packages. It has been known since 1972 that certain old manuscripts become more legible through infrared photography. Earlier use of infrared photography and current use of multi-spectral imaging[1] have become important tools in non-destructive testing of all those objects of an artistic, archaeological or forensic nature that have the characteristics of writing or sketch work, e.g. various inscriptions and manuscripts made with specific types of inks, pencils, coal, etc. on different substrates from papyrus to industrial paper. Although primarily used for detecting underdrawings in paintings, these methods have been successfully applied to the documentation and scientific investigation of documents as well as the evaluation and monitoring of conservation treatments.[2] The term 'hyperspectral imaging' was coined in response to the continuous increase in the number of spectral bands available to multi-spectral cameras.

Representative case studies, selected from a large number handled by the Laboratory of Physical and Chemical Methods for Diagnosis and Documentation at the Department for Conservation of Antiquities and Works of Art, TEI, Athens, during its 25 years of operation, are presented here to illustrate and highlight the effectiveness of these methods. The comparison does not aim to pinpoint the best instrumentation for any given case, but rather to more generally consider the overall advantages, disadvantages and difficulties currently encountered and to suggest the best means of overcoming them.

The documentation of Heinrich Schliemann's copybooks, the investigation of Nikolaos Gyzis' oil sketches on paper and, most recently, the deciphering of the papyrus text from the 'Musician's Tomb' in Daphne, Greece, will be presented as examples.

The use of traditional colour photography (in normal and macro mode), ultraviolet reflection, fluorescence photography and infrared reflectography will be presented as basic steps in an artefact's documentation. Finally, false colour infrared imaging and hyperspectral imaging in the range of 420–1000 nm under normal and raking light combined with simple subtraction algorithms and principal component analysis (PCA) will be assessed as one of the next technological steps in the non-destructive examination of works of art.

2. Case study of Heinrich Schliemann's Copybook Archive

Heinrich Schliemann (1822–1890) was a well-known archaeologist who is particularly celebrated for his excavations at Troy and Mycenae. He was one of the first archaeologists to keep a meticulous archive of data from his excavation sites. His interest in technological advances led him to adopt James Watt's method to facilitate copying his extensive correspondence in a more efficient manner.

[1] Liang 2011; Fisher and Kakoulli 2006.

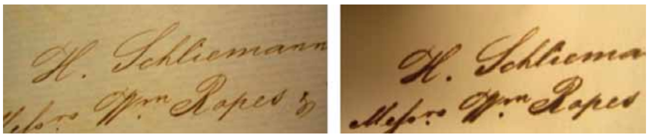
[2] Padoan et al. 2008; Chabries et al. 2003; Banou et al. 2010.

James Watt's copying method, which he patented in 1780, consisted of off-setting the ink from an original document onto a thin, unsized, dampened tissue paper after being pressed with a screw press. The original text was written with a variation of iron-gall ink, which contained Aleppo galls, green vitriol, gum arabic, roach alum, spring water as well as a medium such as glycerin or sugar to prolong drying of the ink to enable copying. The text was transferred as a mirror image to the tissue paper on contact, while the ink penetrated the core of the paper to provide a readable copy on the reverse side (fig. 1).

In situ research carried out in 2004 within the framework of the Archimedes I research programme in public and private archives in Greece[3] traced and examined more than 180 letter copybooks[4] spanning the period 1845–1929. These were used by institutions, shops, businesses and banks in Athens and its surrounding region as well as by private individuals with systematic and extensive outgoing correspondence, among them Heinrich Schliemann, Ioannis Valaoritis, the Greek Olympic Committee, the Byzantine Museum, the National Bank of Greece, the mines of Serifos island as well as shops in Athens and on the island of Kastelorizo. The use of letter copybooks was progressively abandoned after 1915, although examples can be found as late as 1930.

Among the various collections of letter copybooks located in Greek archives, research focused on the Schliemann Archive housed in the Gennadius Library, a part of the American School of Classical Studies in Athens. Only 43 volumes of this extensive copy-book archive survived the First and Second World War and are now included in the comprehensive collection of his private papers. This archive covers the period from 1845 to 1890, and the copies display a wide variety of distinct reproduction techniques and materials that reflect the German archaeologist's special interest in this type of technological development.[5]

From 1845 to 1867 Schliemann copied his letters using loose numbered sheets of copy and accumulated them until they were of sufficient quantity to be bound into books. From 1867 to 1890 he used commercial letter copybooks for this purpose.



original copy

Fig. 1: H. Schliemann's signature in an original and a copy letter.

The study of selected pages from the copybooks was carried out using imaging techniques to record the optical behaviour of the inks at different wavelengths (ultraviolet, visible and near-infrared) and, in this way, document the condition of the copy letters, especially their clarity and readability, and identify the different types of iron-gall copy inks. The methods applied were visible light photography (Vis), ultraviolet reflectance photography (UVR) at 365 nm emission wavelength, ultraviolet fluorescence photography in both black-and-white (UVF) and colour (UVFC), as well as infrared reflectography (IR-Ref) using a digital infrared detector CCD with sensitivity up to 1,250 nm.[6]

Methods were implemented according to protocols based on instrumentation and procedures available at that time, i.e. SLR cameras, optical filters, films and lighting.[7] For better assessment and data management, negatives and colour slides were scanned into digital images in .tiff format[8] immediately after their development.

The great advantage of the equipment used at that time was the capability of black-and-white films to record surface reflectance at 365 nm, monochromatic UV radiation emitted by black-light Philips lamps. Furthermore, film characteristics

[3] Alexopoulou et al. 2006.

[4] The copybooks discussed in this paper should not be mistaken for the copy-books employed by calligraphers and teachers for step-by-step exercises to form capital and small letters of the alphabet.

[5] ASCSA 2005.

[6] Alexopoulou et al. 2012.

[7] The instrumentation for the UV photography included a Canon T70 photographic camera with programmable back for the exposure time and a Canon 50 mm macro lens with an extension tube in order to boost magnification up to 2:1, two Philips HPW 125W 120V and Philips MLW 125W 220V UV black-light lamps as light sources together with the appropriate reflectors, plus the barrier filters Kodak 2E for fluorescence and Kodak 18A for reflection. Images were captured with Kodak Technical Pan film, FujiFilm Provia 100 and Kodak Ektachrome EPR 64 respectively. Visible light photographs were acquired using a Nikon F80 camera with a Nikon AF micro Nikkor 60 mm lens, two Osram 500 Watt tungsten lamps as light sources, two stands with reflectors, Kodak Ektachrome 64T films and the Cokin 82B colour-compensating filter. Exposure time was determined after bracketing. All black-and-white films were developed under the same conditions by the researchers. Infrared reflectography was carried out with a digital infrared camera (CCD, ARTI S.p.A. with a Pentax 50 mm lens) and two Osram 500 Watt tungsten lamps as light sources and two stands with reflectors. The B+W 093 IR-transmitting filter and the B+W 489 heat-absorbing filter were used for visible light and infrared imaging respectively.

[8] Scanning was performed with a Mikrotek ScanMaker 4900 4,800 x 2,400 dpi CCD, 48-bit colour scanner at 1,200 dpi.

in combination with exposure parameters made it possible to control the quality (contrast, value and sharpness) of the primary image in order to achieve optimum results. Even though DSRL cameras now offer flexibility in recording parameters, they still yield poor results for ultraviolet reflection as they are not sensitive to this type of radiation.

The study of Schliemann's letter copy archive mainly focused on the condition of the inked areas, the related phenomena of oxidation and diffusion, and the quality of the copying process.

Ink diffusion is a physical phenomenon that results from blurred ink strokes and can occur during the copying process. It relates to properties of the copy ink and paper, but is mainly due to poor application of the method, usually because of excess moisture, which causes lateral migration of the ink. Oxidation, on the other hand, is a chemical phenomenon due to the migration of the iron ions present in the ink around the ink strokes, which results in degradation of the paper matrix. The stages of degradation range from the formation of a halo around the lines of the ink strokes to expanding discolouration with gradual loss of the paper's mechanical strength around the inked areas and, finally, extensive loss of structural support within the writing itself.

Successful application of the copying method should produce a result comparable to authentic writing while leaving the original document intact. However, copies present differences in quality, characteristics and aging behaviour. In general, copies fall into four categories: (a) excellent, i.e. almost indistinguishable from the originals, (b) good, clear writing with satisfying legibility, (c) bad, faint and uncertain legibility, and (d) poor, with blurred letters and/or seriously pronounced diffusion of the ink, rendering the texts illegible. The structural sensitivity and chemical instability of the copybook materials have challenged archivists, curators and conservators concerning the assessment of their condition as well as the preservation and stability of their data over time.

After the visual comparison of all images obtained at 365 nm (UV), in the visible range of 380–760 nm and in the near-infrared range of 760–1,200 nm, four main categories were identified (table 1).

The first category consists of copies in which the ink and writing appear to be in very good condition. The original writing characteristics have been maintained. Neither intense oxidation nor diffusion in the inked areas nor fading are observed. It should be noted that the phenomena of oxidation and diffusion appear similar in visible light.

The second category consists of copies in which the halo surrounding the inked areas is so extended that the original ink strokes are indistinguishable from the halo. None of the non-destructive methods used practically aided differentiation of the letters from the halos. The IR reflectogram shows high transparency. Only UVFC records a light fluorescence in the perimeter of the letter. This may be the case where the halo is due to ink diffusion during the copying process.

The third category consists of copy letters with thick writing where an intense halo around the writing can be observed. This is probably due to oxidation because the core of the letter can be distinguished clearly from the circumferential oxidation in the visible range and in UV fluorescence colour photography. Only the core is visible in the infrared range.

This last category consists of copy letters in which several areas of diffusion and oxidation may be observed around the letters. A diffusion zone, a thin borderline and a second zone due to oxidation are observed beyond the distinct letter core.

In this case, visible and ultraviolet image capture can make a notable contribution to identifying a distinction between the original ink strokes and the diffusion zones. In the infrared reflectogram, the core of the letter and the pale diffusion around it are evident, while oxidation is not recorded. This, then, is the most helpful category for distinguishing oxidation from diffusion since it consistently presents different and separable visual results in the infrared range.

The methodology which was implemented using the technical facilities of that time helped in reading the texts, distinguishing between oxidation and diffusion phenomena that are quite often present at the same time in the writing, and in providing indications of the quality of ink, its components and, in some cases, the types of inks employed.

3. The Ultraviolet Fluorescence Colour Imaging problem

An important problem, which has arisen from films currently falling into disuse, is the difficulty of obtaining reproducible and reliable images with UV fluorescent stimulation using DSLR cameras. This problem will be presented in more detail in the following discussion.

In the above research, all the ultraviolet fluorescence colour photographs were obtained on film. This method has been studied thoroughly and is thus understood and predictable in terms of its consistent repeatability, so the resulting images maintain a high degree of consistency.

Table 1: Images of the four categories of copy letters at different wavelengths.

Group 1

Group 2

Group 3

Group 4

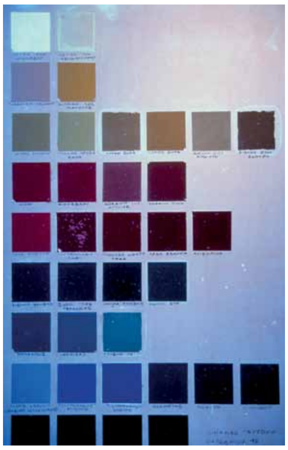
Visible | Ultraviolet colour fluorescence | Infrared reflectogram

As technology advanced and digital cameras became commonplace in visible-light photography, the question arose whether they could be used as reliably and predictably for UV fluorescence colour images. To settle this question, the Laboratory of Physical and Chemical Methods for Diagnosis and Documentation, TEI, Athens, which emphasizes non-destructive testing, conducted a series of experimental comparisons of conventional versus digital captures. These tests were carried out in co-operation with the National Gallery – Alexandros Soutzos Museum (NGA) and the General State Archives (GSA). The aim of these experiments was to closely compare digital images produced by DSLR cameras to matching ones on film produced by conventional SLRs. The question was whether one could ensure the same quality with the DSLR output regarding predictable reproducibility and reliability without any further image post-processing as one could do with film images taken by SLRs.

For this preliminary experiment, three different light sources were tested: Philips MLW125 light bulbs at 365 nm [Philips 2005], Sylvania black-light blue tubes 36W and Osram black-light blue tubes 36W. As for digital cameras, the experiments had to be carried out using the DSLRs already available: Nikon D70s with an AF micro NIKKOR 60 mm lens, Nikon D70s with an AF-S DX Zoom-Nikkor 18–70 mm IF-ED lens, Canon EOS 5D Mark II with a Canon EF100 USM 100 mm lens, and Pentax *istDL with an smc Pentax DA 18–55mm lens. Auto-focus was chosen for all cameras.

A specific test panel was employed as the common target for the shootings: a wooden substrate with a layer of inorganic material (gesso) mixed with organic binding medium (rabbit-

Table 2: Best images for each detector (f5.6, varied speed, Kodak 2E, black-and white 489, white balance [Kodak white card]).



a) Film + SLR

b) Nikon D70s

c) Pentax *istDL

d) Canon EOS 5D MarkII

skin glue) bearing thirty-six tiles 3 cm x 3 cm in size, each with a different pigment. The pigments were chosen based on the fact that they were not only widely employed in works of art, but also well understood and well documented in the international literature as yielding a known and consistent result on film when made to fluoresce in colour by known light sources such as the ones chosen above.

Different white balance settings (cameras' pre-sets of incandescent, fluorescent and daylight conditions or custom setting on different surfaces, i.e. photographic white and grey cards) were tested to see if they influenced the image quality in any way.

These conditions were tested using the Kodak 2E filter, which cuts off ultraviolet radiation as well as excess blue radiation and is considered a standard procedure for conventional analogue images on film. A black-and-white 093 (equivalent to Kodak Wratten 87C) visible-radiation (up to 780 nm) cut-off filter was also employed to test whether infrared radiation affected the images. Both CCD and CMOS sensors in digital cameras are considered sensitive in the near-infrared range despite there being filters incorporated in their main body to cut off unwanted IR radiation from being recorded. It has often been reported that these cameras are not completely free from infrared interference. The outcome necessitated further testing with an IR cut-off filter, the black-and-white 489, to improve image quality.

It soon became clear that, even when using extra filters, a small amount of infrared radiation could not be avoided, which therefore affects the final image to a greater or lesser extent, depending on the camera. It should be noted that reversal (i.e. slide transparency) films, when employed in conventional analogue (film) cameras, are not sensitive to infrared radiation and thus produce IR-free images.

After thorough experimentation and readjustment of the image acquisition parameters, the DSLR camera equipment (Nikon D70s/AF micro NIKKOR 60 mm lens, Nikon D70s/AF-S DX Zoom-Nikkor 18-70 mm IF-ED lens, Canon EOS 5D Mark II/Canon EF100 USM 100 mm lens and Pentax *istDL/smc Pentax DA 18-55 mm lens) exhibited different behaviour in UVFC photography than the equivalent SLR-and-film system (table 2). Furthermore, even though the DSLR cameras were used under the same conditions, the resulting images were not reproducible. Nonetheless, by using the final experimental combination,[9] it is possible to study fluorescence by achieving an image quality that at least differentiates the fluorescent colour between pigments.

4. Case study of Nikolaos Gyzis' sketches and signatures

Nikolaos Gyzis is considered to be one of the most important Greek painters of the 19th century. He initially studied painting in Athens and later in Munich, where he worked under Hermann Anschütz and Alexander von Wagner at the Academy of Fine Arts. In 1868, he was accepted into Karl von Piloty's class. Gyzis is a dominant figure in the 'Munich School' movement. He not only influenced the course of Greek art with his painting, but also occupies an important place in the history of 19th century German art. His versatile artistic personality promoted the creation of a

[9] Best results for DSLR detectors: Nikon D70s, f5.6, varied speed, Kodak 2E, black-and white 489, white balance (Kodak white card).

Fig. 2: 'Spirit', Nikolaos Gyzis, bilateral, head and torso of a young boy, possibly an angel (both sides). Late 19th c.

complex opus that transcended the level of mere narration, with his true merit showing in his idealistic, allegorical and religious work – fields in which he was in step with the aims of the *Jugendstil* avant-garde movement. In addition to genre painting, he worked on still lifes and portraiture as well as producing idealistic allegorical subjects, ethnographical scenes and poster art. He proved that he could master a broad range of artistic expression to further his personal ideas and visions.

Two aspects of his work were studied in our imaging analysis of Gyzis' painting: his sketches and his signatures.

Nikolaos Gyzis' oil painting commissions were usually quite large in size, so it was customary for him to prepare sketches using oil-on-paper substrate in order to visualize what he had in mind. Oil-on-paper is very delicate and requires careful conservation treatment in order to ensure an optimal state of preservation. As part of the Costopoulos Foundation Research Programme (2010) and the Archimedes III Research Funding Programme (2012–14), oil-on-paper paintings of Nikolaos Gyzis were examined in order to study the behaviour of oil in interaction with the paper substrate and whether oxidation of the paper is enhanced or suppressed by the oil medium.[10] Several non-destructive examination techniques were employed, but the following example merits particular attention.

The oil sketch 'Spirit', catalogue number Π588, which belongs to the main collection of the National Gallery – Alexander Soutzos Museum, attracts special interest for two reasons: not only does it show links to other important works of the artist, but it is also bilateral in presentation (fig. 2). In this work, Gyzis depicts the head and torso of a young boy on both sides of the paper support. On the recto, he sketched a child figure, which resembles an angel, exclusively by applying coloured oils, mostly red, blue and brown, both in thin (diluted) and thick layers. On the verso, he depicts much the same figure using some kind of pencil. The head is detailed while the torso is executed in a somewhat more simplified and impressionistic fashion. Comparative study of the two sides of the work has shown that the painted figure corresponds to the black-and-white sketch. Although there

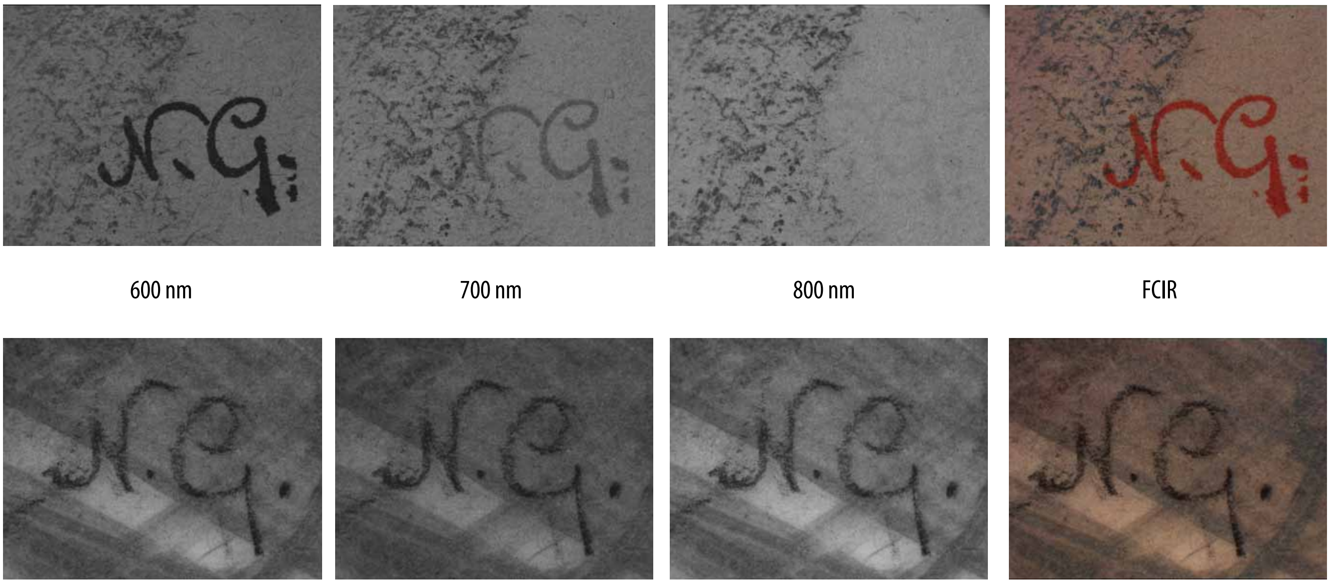
[10] Banou et al. 2010.

Visible UVR UVFC FCIR IR Ref

Fig. 3: 'Spirit', Nikolaos Gyzis, detail, images at different wavelengths.

are a few differences in the movement of the hand as well as the position of the head and the hair, the two images seem to be intentionally connected. However, each image exhibits a number of specific stylistic characteristics. Based on observations of published pictures of Gyzis' works, charcoal and chalk portraits are usually detailed, expressive and atmospheric with emphasis on light denoted by the use of white chalk. By contrast, oil sketches are more freestyle, without details or strictly defined forms. They are executed naturally and unconstrained by stricter artistic boundaries.

Hyperspectral imaging and false colour infrared imaging[11] were applied to both sides of the painting (fig. 3). These images, combined with UVR and UVFC recordings, permitted differentiation of the different types of materials the artist used for the sketch: the intense black strokes on the eyelids, the mouth and the left side of the head (relative to the viewer) exhibit strong ultraviolet absorption (black) and infrared reflectance (soft grey to white) in contrast to the grey-black drawing material the artist employed in the remainder of the sketch, which presents absorption (dark grey) at all wavelengths. According to Attas,[12] black and dark drawing materials exhibit different behaviour in the infrared range. For example, carbon black absorbs light strongly and is therefore darker than graphite, which exhibits medium



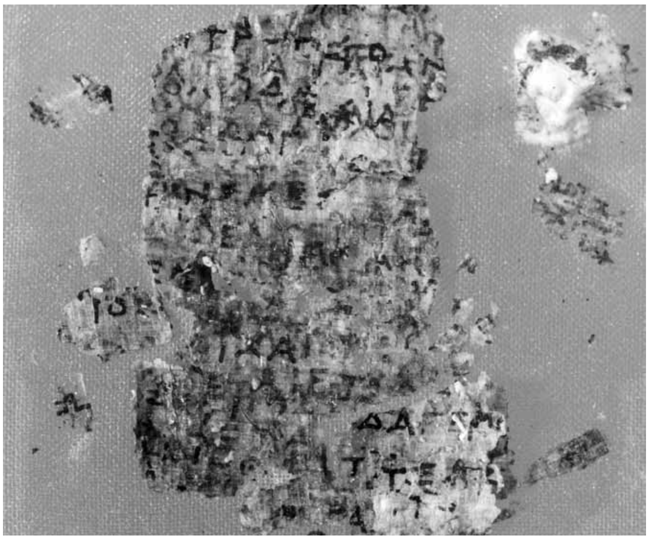
600 nm 700 nm 800 nm FCIR

Fig. 4: Nikolaos Gyzis' signatures from 'Spirit' (above) and 'Study Π581_1' (below) at specific wavelengths.

[11] MuSIS HS by Forthphotonics (now DySIS) 400–1,000 nm with 20 nm interval and 34 spectral bands, Schneider-Kreuznach XENOPLAN 1.4/23 CCTV lens, Osram 250W tungsten light sources.

[12] Attas et al. 2003.

Visible



Infrared at 1,000 nm

Fig. 5: The Musician's Tomb papyrus MP8523 fragment, approx. 2.3 cm x 3.5 cm.

absorption. This differentiation of materials can also be observed in the false colour infrared image (FCIR), in which the former material presents a greenish hue, but the latter a sepia one. Another interesting aspect that can be observed in the ultraviolet fluorescence colour image (UVFC) is that the sketch is free of brushstrokes. The brushstrokes are on the reverse side and were only visible because of the transparency of the paper. They disappeared because fluorescence is a phenomenon that only pertains to an object's surface.

Gyzis' signatures were examined to study and document the different media the artist used to sign his work. Hyperspectral imaging was used for this reason. Black-and-white images of the signatures in the visible and infrared range were acquired in narrow bandwidths to track the inks' reflective behaviours. As can be seen in fig. 4, the selected images from hyperspectral imaging at 600 nm, 700 nm and 800 nm clearly present the gradual decrease in absorption of the first ink and the unchanged absorption of the second ink. While infrared reflectography produces images pertaining to the entire near-infrared range (760–1,000 nm), in hyperspectral imaging, wavelengths are recorded at specific intervals. This enables changes to be observed and tracked that take place in the infrared range. Furthermore, hyperspectral imaging cameras provide important information on the materials through false colour infrared images, which were obtained and compared with each other for the signatures. Red false colour can be typical of iron-gall inks, while black can be for carbon-based inks or pencils.

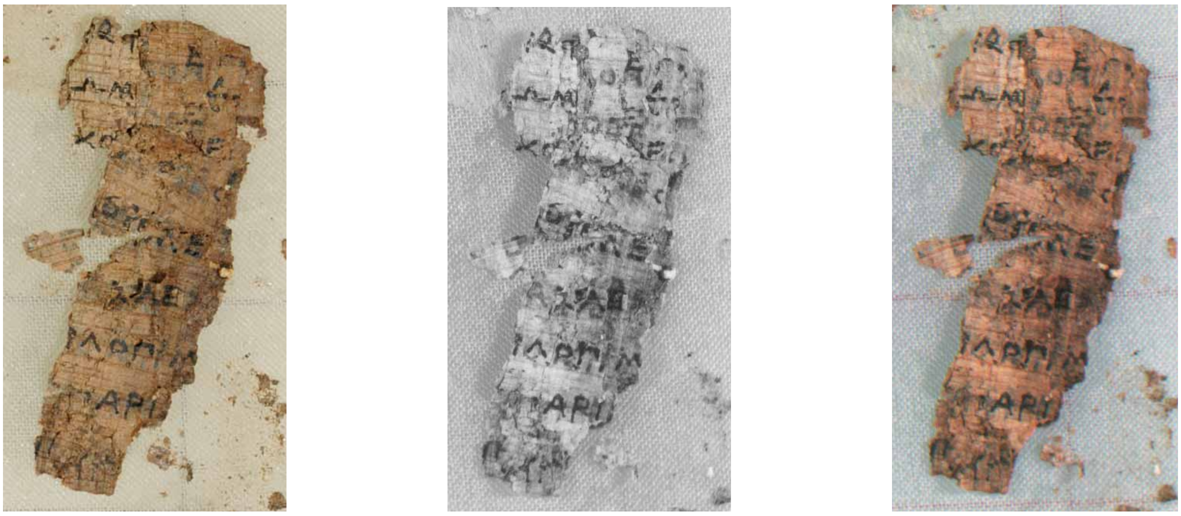
The same apparatus enabled the acquisition of a reflectance spectrum. This revealed the inks' visible and near-infrared characteristics, which proved to be very effective in tracking and distinguishing data produced from different depths with greater precision and resolution when compared with classic reflectography. Hyperspectral imaging combined with the raking light technique provided information-enriched images due to the surface texture, thus making discrimination between the signing media possible.

5. The papyrus found in the 'Musician's Tomb'

'Greek artist's grave yields rare papyrus' – this was the headline of an article by the Athenian correspondent of the British national daily *The Times* in May 1981 announcing that two tombs dating to 420/430 BC had been found during an emergency excavation in Daphne, Athens.[13] One of the tombs contained, among other artefacts, parts of musical instruments, writing tablets and a papyrus, thus leading the archaeologists to name it the 'Musician's Tomb'. Although the papyrus was at first considered completely destroyed and incapable of any reclamation, special significance had to be attributed to it and to the *polyptychon* tablets as they are the oldest Greek text testimonials found in Greek territory to date.[14]

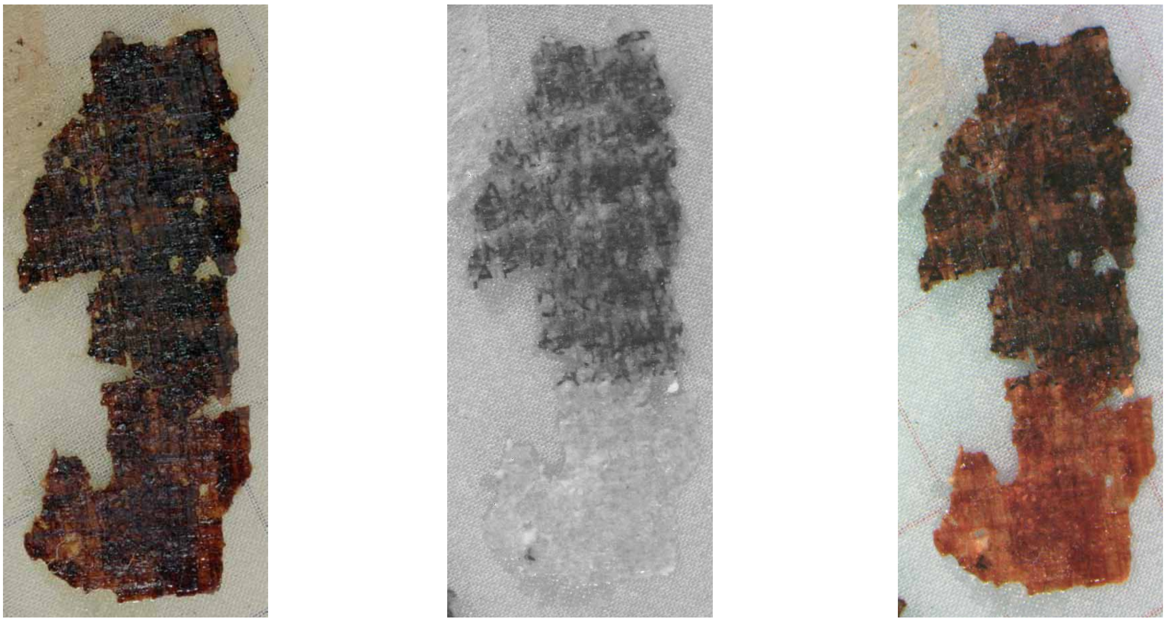
[13] Alexopoulou et al. 2013; Alexopoulou and Kaminari 2013.

[14] West 2013.



visible infrared at 800 nm FCIR

Fig. 6: the Musician's Tomb papyrus MP8520 fragment 1, approx. 3.1 cm x 1.4 cm.



visible infrared at 1,000 nm FCIR

Fig. 7: The Musician's Tomb papyrus MP8520 fragment 2, approx. 1.6 cm x 4.8 cm.

The papyrus, decayed into an amorphous mass of nearly rotten fibres,[15] comprised several leaves pasted together. A white material resembling plaster had destroyed most of the upper portion. The conservator in charge carefully separated as many fragments as he could from the formless mass, placed them onto an organic silk fabric in wooden frames and consolidated and restored them. The papyrus and all the other finds are now kept at the Archaeological Museum of Piraeus.

In some cases, one could observe more letters on the surface in various places with orientations or further letters appearing between the lines. In the inventory, these were assumed to be probable musical notes, and this was one of the critical questions to investigate since this element would be very important in the interpretation of the finds (fig. 5).

The main concern in this research, carried out in 2012, was to somehow revisualize and thus reclaim written data from

[15] Pöhlmann 2013.

underneath layers of papyrus, which were found mashed together in the tomb before being transferred together to their current holding place, as well as to facilitate making the dark fragments of papyrus legible.

Hyperspectral imaging combined with principal component analysis (PCA) and image segmentation techniques were employed for these reasons. Spectral image cubes were acquired at visible and infrared wavelengths to differentiate the script from elements pertaining to the condition of the object, e.g. scratches, deposits, etc. False colour mode also enhanced our ability to collect more information on the script reclaimed from the papyrus as well as on issues related to the investigation of the writing both in terms of overall legibility and discerning individual letters of the text. Fragments that had turned dark due to chemical consolidants applied during conservation were rendered clearer and the script again became more readable (figs. 6 and 7). As images were difficult to interpret by the unaided eye since they contained information from different layers, image segmentation, image subtraction and the well-known application of PCA were used to optimize the extraction and differentiation of information. The resulting images showed clearly distinguishable areas of text, the layers of the papyrus were differentiated from one another better and letters that belong to the same sheet were able to be grouped together with greater confidence.

To complete the investigation of the Musician's Tomb papyrus, an effort was made to capture digital photographs in macro mode in the visible spectrum using the newly developed digital Nikon D800, which employs a Nikon FX-format CMOS sensor with 36.3 effective megapixels' resolution. This photographic apparatus was employed in order to collect the maximum amount of readable information from the fragmentary remnants of words and letters on the papyrus, which initially seemed to resist successful imaging.

In conclusion, for objects whose significance and fragility demands special care and which do not allow for physical sampling, these non-destructive test methods assisted by image-processing techniques are the best approach as these reveal information from a certain depth near the surface of the object as well as from the surface itself. False colour imaging differentiates relevant features from scratches and yields better results for distinguishing them when compared with single wavelength recording. Currently, a photographic apparatus with extremely high resolution and optical quality seems to be a low-cost tool for macro-mode investigation.

6. Conclusions

The case studies presented here are just part of the research activities carried out using equipment available at various times. Each case had its own needs and presented a unique set of problems and limitations. This paper has shown that it is possible to study artefacts and obtain useful images capable of yielding significant scholarly results regardless of the restrictions encountered.

These case studies have also made it clear that even though technology has facilitated image acquisition from manuscripts and works of art by exploiting a wide range of wavelengths, the comparative interpretation of the results requires a very careful approach to be taken based on the structure and chemistry of the materials. Optical data must always be correlated with physical and chemical properties, morphology, aging and construction technology for individual objects.

ACKNOWLEDGEMENTS

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