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# SPECTRAL OBJECT DOCUMENTATION
# COSCH WORKING GROUP 1
# REPORT ON ACTIVITIES 2012–14

Marcello Picollo [a],*, Sérgio Nascimento [b] , Tatiana Vitorino [c]

[a] COSCH WG1 Chair, Istituto di Fisica Applicata “Nello Carrara” - Consiglio Nazionale delle Ricerche
(IFAC-CNR), Florence, Italy –
m.picollo@ifac.cnr.it
[b] COSCH WG1 Vice-Chair, Departamento de Física, Universidade do Minho
Campus de Gualtar, 4710-057 Braga, Portugal
[c] COSCH WG1 member, Department of Conservation and Restoration, Faculdade de Ciências e Tecnologia,
Universidade NOVA de Lisboa, Campus da Caparica, 2829-516 Caparica, Portugal,
and IFAC-CNR, Florence, Italy
tatianamfv@gmail.com

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**ABSTRACT**: This interim report covers the activities of the Working Group 1 (WG1) of "Colour and Space in Cultural Heritage" (www.cosch.info), the COST Transdomain Action TD1201, supported by the European Cooperation in Science and Technology between 2012– 2016. The report covers the period from 2012 to 2014. Spectral imaging techniques have been increasingly applied to the study and documentation of cultural heritage objects in the past years, and a large number of sophisticated and varied instruments has been made available. The activities of COSCH WG1 focus on the identification, characterisation and testing of two-dimensional multi- and hyper-spectral imaging techniques in the Vis-NIR-SWIR regions, and beyond, in this context. Concerning the many difficulties with accessing, processing and comparing the data obtained with different imaging devices, the group is working towards the development of standardised methodologies and most efficient practices regarding the application of these techniques in the art conservation field, taking into consideration the needs of various cultural heritage end-users. The present interim report introduces the purposes and development of spectral imaging techniques in the field, and the reasons for gaining a better understanding of spectroscopic instruments and the elements of data acquisition; it also proposes to define terminology. The report presents the round robin test developed by the working group, which has focussed on typical cultural heritage objects and questions commonly posed in the art conservation field. This test aims to explore and compare characteristics and performances of spectral imaging devices and approaches developed by different research groups, and to understand their impact on data accuracy. The final version of the report will shed light on the challenges and difficulties faced by end-users, and ensure the usefulness, reliability and comparability of the data from different instruments and institutions.

As stated in the Colour and Space in Cultural Heritage (COSCH) TD1201 COST Action Memorandum of Understanding, true, precise and complete documentation of artefacts is essential for conservation and preservation of our cultural heritage (CH). It is therefore important to define which kind of objects belongs to our CH. The UNESCO Database of National Cultural Heritage Laws stipulates, in the document *Dealing in Cultural Objects (Offences) Act 2003, Chapter 27*, that “a cultural object means an object of historical, architectural or archaeological interest” [1]. In addition, the Visual Resources Association, in its publication *Cataloging Cultural Objects: A Guide to Describing Cultural Works and Their Images*, defined a CH work as “a distinct intellectual or artistic creation limited primarily to objects and structures made by humans, including built works, visual art works, and cultural artefacts” [2].

Bearing those definitions in mind, the activities of COSCH Working Group 1 (WG1) are mainly focused on the identification, characterisation and testing of two dimensional (2D) spectral imaging techniques in the visible and near infrared (IR) field (task st1.1) and on the identification, characterisation and testing of imaging techniques beyond the visible and short wave radiation (task st1.2) for the study and documentation of CH artefacts. These tasks brought together research groups with different backgrounds and diverse research applications and aims. However, most of the efforts have been dedicated to the application of spectral imaging techniques to the investigation of artworks, mainly two-dimensional objects such as paintings.

## 1. INTRODUCTION

In order to provide the right tools for curators, museum registrars, conservators, archaeologists, conservation scientists and connoisseurs to understand, gain knowledge of, and preserve the cultural heritage of the world, it is important to study, analyse, and characterise the materials used in the making and conservation of artworks [3,4]. In the eighteenth century, when the first scientific investigations of works of art and archaeological objects were conducted, the art historian Johann J. Winckelmann (1717–1768) stressed the fact that art history could not be separated from a thorough understanding of the materials constituting a particular artwork and the knowledge of the components that were used for creating it [5]. Subsequently, in the first half of the twentieth century the availability of more sophisticated and reliable analytical instrumentation gave a strong impulse to the scientific conservation field, particularly in UK and the United States. From then on there has been a rapid growth in the study of materials used in ancient and modern artworks all over the world [6]. Moreover, it has been evident that this study of artists' materials and their application to the various techniques of creating art covers a number of separate subjects, which, however, are largely interrelated [7].

Presently, the study of the materials constituting artworks and archaeological objects can be performed using invasive and/or non-invasive approaches [4]. Commonly, the invasive techniques require samples from the investigated object. In the study of artworks such as paintings, they are also called micro-invasive investigations due to the microscopic size of the sample requested for the analysis. Non-invasive techniques do not have this drawback, even though they are not completely exhaustive. However, these last techniques can be very useful for locating areas for micro-sampling or for extending local data from micro-analyses to a broader scale, thus reducing the extent of micro-sampling operations. Non-invasive methodologies are mainly performed by investigating small (spot size or 1-D technique) and wide (2D technique) areas, and are focused on the diagnosis, study and conservation of, as well as on the access to, objects of art. Preliminary non-invasive approaches are always necessary at the beginning of the study and/or investigation of a work of art, or before initiating any conservation procedure on valuable objects, in order to assist curators and conservators in their decision-making process.

When dealing with artefacts that can be considered nearly flat objects, such as paintings, drawings or other graphic artworks, imaging (2D) techniques offer an ideal approach for performing non-invasive, yet in-depth, examinations. In the field of art conservation, these imaging techniques range from well-established methodologies, such as visible light photography/imaging techniques (normal, raking, specular, transmitted), ultraviolet-induced fluorescence and reflected ultraviolet imaging, trans-illumination and trans-irradiation imaging techniques, infrared photography, infrared reflectography, infrared thermography, X-ray radiography, digital and computed X-ray radiography and tomography, neutron activation autoradiography, and photogrammetry [8-16], to cutting-edge applications, like ultraviolet-visible, near-infrared, and luminescence imaging spectroscopy, terahertz imaging, reflectance transformation imaging, and synchrotron imaging techniques [17-39].

These cutting-edge techniques could be grouped in multi-band, multi-spectral and hyper-spectral methodologies depending on the number of bands selected over a given spectral interval and on their bandwidths. In the past, some European research projects focused on 2D multi-band and multi-spectral imaging capture. Examples are the CRISATEL, EPOCH, NOESIS, and VASARI projects, which emphasised the importance of colour definition on cultural heritage objects [40-43]. Indeed, accurate colour reproduction is one of the most important requirements for imaging techniques aimed at digital archives for the documentation and study of artworks. Moreover, the analysis of chromatic and spectral characteristics is important, not only to make a reliable reproduction of the artwork that can be available at any time, but also to provide quantitative and objective information on the conservation state of the object. In addition, some of those 2D techniques could provide useful data on the identification of artists' materials, such as pigments and dyes, and the mapping of their distribution on the investigated surface.

However, there are still no well-established and commonly accepted standards for a precise, non-contact study and documentation of artworks that could implement and combine the above mentioned techniques. Therefore, one of the COSCH Action tasks is focused on creating and proposing recommendations for colour and spectroscopic measurements through the use of imaging systems. This will provide the art conservation community with guidelines for the most common applications.

In fact, the WG1 of the COSCH Action mainly focuses on the theoretical identification and practical exploration of important characteristics of instruments and their potential impact on data quality and accuracy, usability and information content with respect to typical surfaces (PT1). This task is divided into two sub-topics titled "Identification, characterization and testing of spectral imaging techniques in the visible and near IR field" (st1.1) and "Identification, characterization and testing of imaging techniques beyond the visible and short wave radiation" (st1.2). The first sub-task (st1.1.) was defined since spectral imaging techniques have undergone a comparable change in technology, as have spatial imaging techniques. New developments in optical techniques led to novel ways of splitting the radiation resulting in new characteristics of instruments dedicated to monitor the optical spectrum of imaged surfaces. It is therefore necessary to explore the limits and advantages of the actual instruments in these wavebands. The second sub-task (st1.2) is more directed to the study of the interaction between the physical and chemical composition of surfaces and radiation. As not all of these interactions have an impact in the visible spectrum, it was decided to exploit and qualify also the data obtained with instruments working outside the visible range, mainly in the infrared and THz regions since these are often essential for the analysis of the surfaces' composition.

Hence, the main activity of WG1 has been focused on the standardisation of the acquired imaging data and the calibration procedures to be followed with the diverse imaging systems. In particular, great emphasis has been placed on creating a well-defined and structured Round Robin Tests (RRT) in order to compare colour and spectroscopic measurements, as well as information on calibrated standards and laboratory mock-ups obtained through the use of diverse imaging devices developed by the different research groups that participate in the COSCH Action. The final report of this activity will provide the art conservation community and the scientists working in colour and spectral imaging acquisition, with reliable documentation about the best measurement procedures to be followed by users, starting from the most immediate applications, such as the acquisition of accurate RGB images using an RGB camera, up to sophisticated hyper-spectral systems capable of high spatial and spectral resolution. In addition, the standard procedures for the acquisition and elaboration of images, as well as the definitions needed to help the final users to understand the technical terminology, will be documented and made available.

## 2. REVIEW OF EARLIER RESEARCH

Starting from the information on some projects dealing with the implementation, use and application of colorimetric and spectroscopic imaging methodologies in the art conservation/documentation field, it is clear that even though a lot of efforts have been made to provide guidelines and standardise those methods, there is still the need of further research activities focussed on a greater standardisation of the application of the above mentioned imaging techniques, in particular under the end-users' point of view.

In the following paragraphs, a short selection of some recently financed EC projects inherent to new trends in the digital technologies developed for the CH sector is presented. However, the list reported is not exhaustive, since it aims at selected examples of the technological issues tackled in the research of the last years.

The INSIDDE project (Integration of technological solutions for imaging, detection, and digitisation of hidden elements in artworks, 2013-2015, FP7 ICT-2011-9) is focussed on the development of graphene-based transmitters and receivers working in different frequency bands within the submm-wave/terahertz range. This is expected to allow, together with image processing techniques and a high-resolution structured light scanner, the identification of pigments, brush-strokes or underdrawing in paintings, as well as to look inside sealed pottery.

The CHARISMA project (Cultural Heritage Advanced Research Infrastructures: Synergy for a Multidisciplinary Approach to Conservation/Restoration, conducted under the FP7 Research Infrastructures Programme, http://www.charismaproject.eu/) developed new optimised methodologies for the acquisition and processing of images in order to investigate the 2D and 3D distribution of organic and inorganic materials on art objects. While developing new optimised multispectral imaging methodologies, emphasis has been placed on the use of equipment that is readily available and distilling the work carried out into a set of user-friendly practical materials and resources, which are aimed at a wide range of users and are as broadly accessible as possible. In this way, it is hoped that these are not only widely adopted by the cultural heritage community, but also address the needs of users beyond it.

SYDDARTA (SYstem for Digitization and Diagnosis in ART Applications, 10.2011-3.2014, FP7-ENV) developed a prototype for monitoring movable cultural assets. This was achieved by using three-dimensional (3D) hyper-spectral imaging, where hyper-spectral images are acquired whilst simultaneously scanning the 3D profile of the object.

3D-COFORM (Tools and expertise for 3D Collection Formation, 12.2008-11.2012, FP7-ICT) addresses all aspects of 3D-capture, 3D-processing, the semantics of shape, material properties, metadata and provenance, integration with other sources (textual and other media), search, research and dissemination to the public and professional alike. A strong technical research program is complemented by research into practical business aspects: business models for exploitation of 3D.

FING-ART-PRINT (Fingerprinting Art and Cultural Heritage - In Situ 3D Non-Contact Microscale Documentation and Identification of Paintings and Polychrome Objects, 11.2005-4.2008, FP6-POLICIES) devised a system to make "fingerprints" of works of art so that they can be identified. A combination of 3D surface scanning and multi-spectral imaging provides a unique data record of the object, which can be compared to check its authenticity.

ECHASE (Electronic Cultural Heritage Made Accessible for Sustainable Exploitation, 1.2005-12.2006, ECONTENT) sought to demonstrate that public-private partnerships between content holders and commercial service providers can create new services and a sustainable business based on access and exploitation of digital cultural heritage content.

EPOCH (European Research Network on Excellence in Processing Open Cultural Heritage, 3.2004-3.2008) combined expertise and resources of technologists, heritage administrators, heritage professionals and communication experts concerned with the effective and sustainable application of digital technology to archaeological research and cultural heritage presentation at museums, monuments, and historic sites.

RECOVER (Photorealistic 3D Reconstruction of Perspective Paintings and Pictures, 10.2005-9.2007, FP6-SME) developed a system for the semi-automatic extraction of 3D models of scenes depicted in perspective paintings. This project will capitalize on a vast body of research knowledge, in order to bridge the gap between state-of-the-art and state-of-practice in the construction of 3D models from 2D paintings. By doing so, the resources required for constructing such models will be drastically reduced, thus increasing the competitiveness of the companies commercialising the underlying technology.

NOESIS (Non-destructive image-based manuscript analysis system, 9.2004-8.2007, FP6-INCO) produced non-destructive non-invasive image-based processing techniques to aid the historical analysis and examination of five significant Mediterranean collections of manuscripts. Digital images from the manuscripts captured in visible colour, ultraviolet and monochrome infrared will be used to derive computational profiles of the inks and support.

CRISATEL (Conservation Restoration Innovation Systems for image capture and digital Archiving to enhance Training, Education and lifelong Learning, 9.2001-8.2004, FP5-IST) developed a technology and information environment to preserve paintings by ultra-high quality multi-spectral digitisation, to preserve the created digital resources in long term, to enable the use of the images as surrogates, and to assist conservation of the originals.

The outcomes of these research projects [33, 44, 45], alongside advanced studies carried out in parallel in many laboratories and research institutes, have provided a well-grounded know-how, as well as several prototypes of instrumentations specifically designed for high-quality digital imaging of artworks and for conservation purposes [17, 21, 22, 46-49].

In this context, COSCH WG1 management decided to further explore the possibilities offered by different technical and methodological approaches for the acquisition of multi- and hyper-spectral imaging data. This activity has also been focussed on the implementation of knowledge, guidelines, good practices and standardised methodologies with respect to the application of the numerous spectral imaging devices used to study and document cultural heritage. In fact, current research projects and results on diverse topics through the application of different technical and methodological approaches showed the great difficulties in comparing the data obtained with the different imaging devices and in making those data easily accessible (see list of presentations in section 6) and ready to be used by end-users.

## 3. DISCUSSION OF THE CHOSEN APPROACH AND METHODS

Among the above mentioned 2D techniques (see section 1), spectral imaging has been applied as an *in situ* method for the study and accurate digital documentation of artworks, and an increasing number of devices has been developed for such purpose. However, depending on the system used, data accuracy and reliability may vary. For this reason 2D-object test samples of different typologies were carefully selected to be used in a Round Robin Test (RRT). This RRT exercise is being carried out by WG1, within a coordinated research effort that aims to identify the characteristics and performances of different spectral imaging instruments, and to standardise methodologies for the analysis of various types of artworks with those instruments, therefore ensuring the usefulness, accuracy and comparability of the data acquired. In this RRT, the same 2D-object test samples have to be measured in different laboratories and the results obtained by each group have to be compared. In each case, the working conditions and technical parameters are not predetermined, since the point is that each group uses the setup commonly applied in its laboratories. In addition, the individual setups are carefully documented by each group.

The set of five selected 2D-object samples is:

- Round Robin Test 1 (Figure 1): X-Rite® ColorChecker Classic (provided by M. Hauta-

Kasari), 280 mm x 216 mm, used to define the characteristics of each imaging device in colour rendering. It is a matt chart with twenty-four standard coloured square patches, each with 40 mm of side, that include the representation of true colours of natural matter (such as skin, foliage and sky), additive and subtractive primary colours, various steps of grey, and black and white (see Figure 1). Presenting the different colours in a 4 by 6 array, and with a dimensional scale, this standard is used as a colour reference to evaluate colour reproduction processes, to guarantee that the information obtained is valuable and represents the true colours of the object that has to be studied and documented.

Figure 1. The X-Rite® ColorChecker Classic reference chart used in the WG1 RRT.

- Round Robin Test 2 (Figure 2): X-Rite® White Balance (provided by M. Hauta-Kasari), 280 mm x 216 mm, used to define the level of homogeneity in illumination during the image acquisition and in detector elements. It is a full-size version of the white reference square from the X-Rite® ColorChecker Classic and presents a spectrally neutral and uniform surface under any lighting condition.

Figure 2. The X-Rite® ColorChecker White Balance reference chart used in the WG1 RRT.

- Round Robin Test 3 (Figure 3): SphereOptics Zenith Polymer Wavelength Calibration Standard (provided by A. Jung), a new reference panel of PTFE mixed with a combination of three rare earth oxides (holmium oxide, erbium oxide, dysprosium oxide), used to define the spectral accuracy and resolution of each imaging device. It is a stable and chemically inert reflectance standard, with ca. 90 mm of diameter and ca. 15 mm of height, and an opaque, homogenous and smooth surface. Displaying sharp absorptions at specific wavelengths covering the UV-VIS-NIR region of the electromagnetic spectrum, it is commonly used for establishing the accuracy of the wavelength scale of reflectance spectrophotometers.

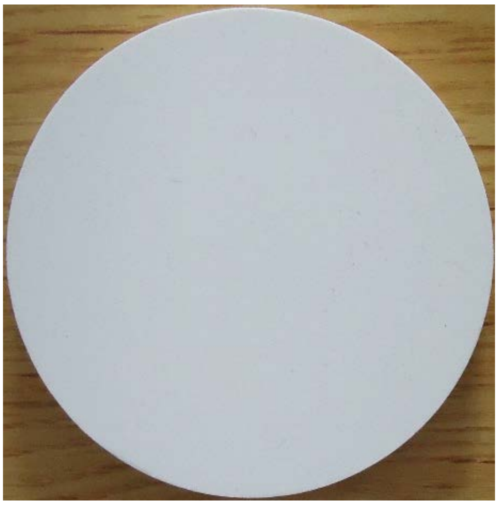

Figure 3. The cylinder-shaped SphereOptics Zenith Polymer Wavelength Calibration Standard used in the WG1 RRT.

- Round Robin Test 4 (Figure 4): Antique Russian icon (1899) printed on tin plate glued to a wooden support, 26.5 cm x 22.0 cm (provided by L. MacDonald). It represents the Virgin of Kazan and is marked “Moscow 1899”. From unknown provenance, the icon was purchased from Estonia. Its surface presents specular reflectance from pseudo-golden areas and the composition of the coloured materials is unknown. This object was chosen to stress the behaviour of the different imaging devices when highly reflective surfaces, such as the gold background, are investigated. The icon was selected also to assess the systems’ spectral resolution for the identification and characterisation of the unknown coloured materials, and to establish the systems’ performance while documenting the object with high accuracy.

Figure 4. The Russian icon on tin plate used in the WG1 RRT.

- Round Robin Test 5 (Figure 5): A test panel painted with medieval Tuscan technique (provided by M. Picollo) produced to highlight the performances of the different imaging devices in penetrating the paint layers and detecting the under-drawings. This object is also useful to stress the importance of having reference materials, which preparation is known, in order to help in the identification of artists' materials through comparison with their spectral reflectance. The painted panel (approx. 12 cm x 29 cm) was reconstructed by Elena Prandi and Marina Ginanni (Restoration Laboratories of the former Soprintendenza SPSAE e per il Polo Museale della città di Firenze, Italy), in order to reproduce the medieval Tuscan technique as described by Cennino Cennini. For the reconstruction, a glue layer and a gypsum ground layer were applied on a wooden support. After this first gypsum ground layer, a canvas was applied, followed by a second gypsum ground layer, on top of which various lines and drawings were done with different materials (lead-based metalpoint, lead- and tin-based metalpoint, graphite, charcoal, and watercolour) and techniques (lines, *spolvero*, *sfumato*) in an attempt to reproduce the various ways in which underdrawings were done in the past. Finally, coloured paints with egg tempera (2 parts yolk + 1 part glair + 1 part white vinegar) were applied with different thickness (each coloured paint has a more transparent layer on the left and a more opaque layer in the right), using the *tratteggio* technique, which resulted in layers that are not homogeneous. The following pigments from Zecchi were used: Burnt Umber (manganese hydroxide and oxide with iron hydroxide), Carmine (carminic acid lake), Vermilion (mercury(II) sulphide, HgS), Malachite (basic copper carbonate, $CuCO_3{\cdot}Cu(OH)_2$), Azurite (hydrated copper carbonate, $2CuCO_3{\cdot}Cu(OH)_2$), Lead White (basic lead carbonate, $2PbCO_3{\cdot}Pb(OH)_2$), and Ivory Black (phosphorus, calcium and magnesium with carbonate). These colorants were chosen since they were commonly applied with the egg tempera technique. Not only that, all of them present strong absorption bands in the visible range and different behaviours with respect to the NIR region (for example, Carmine is very transparent in the NIR, while Burnt Umber is opaque), which can be useful to assess the systems' performance regarding different characteristics of the materials in both ranges.

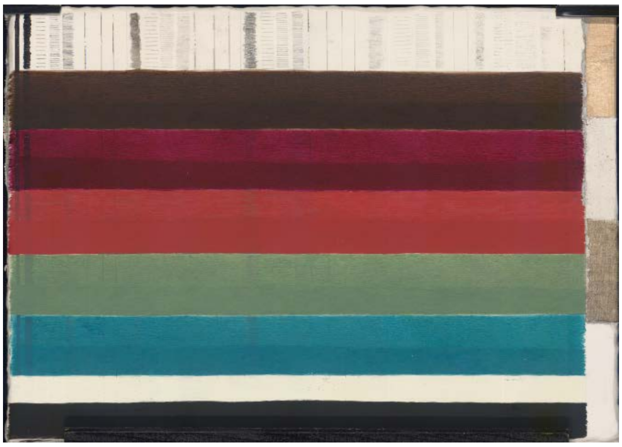

Figure 5. The painted panel reconstructed with medieval Tuscan technique used in the WG1 RRT.

At the beginning, approximately ten groups joined the RRT. To date, eighteen research groups have been involved in the RRT. They are listed in Appendix 1.

Sony George (Gjovik University, Norway) was nominated as the person in charge of keeping track of the shipping of the samples during the RRT and organizing the test. At the end of 2014, approximately 50% of the groups have acquired the data on the RRT objects. The data acquisition process proceeded slower than expected due to summer vacations and machine-time availability at each laboratory. Moreover, new research groups have decided to join the RRT in the past months thus increasing the number of laboratories to coordinate.

The RRT data will be used to define the characteristics of each imaging device in colour rendering and spectral accuracy and resolution. Moreover, these data will serve to stress the behaviour of the different imaging devices when highly reflective surfaces, such as gold backgrounds, are investigated. Finally, the performances of the different imaging devices in penetrating the paint layers and detecting under-drawings, as well as in the identification and mapping of different artists' materials will be evaluated.

Within this context, the experience gained at the IFAC-CNR laboratory on the acquisition and processing of the imaging spectroscopic data and on the type of results obtained, in order to explore the advantages and limitations of the IFAC-CNR push-broom hyper-spectral imaging system in the visible and near-infrared range, is reported as an example. The information gathered and presented in this report will be the starting point for the handling, articulation and comparison between all the data from the twenty institutions. Ultimately, the outcomes of the RRT will help us to define good practices and lead us to the state-of-the-art study and documentation of cultural heritage through the use of these non-contact high-resolution optical techniques based on an optimised and adapted use.

## 4. MAIN FINDINGS

*Round Robin Test 1: X-Rite® ColorChecker Classic*

To assess the accuracy of the colour image processing of IFAC-CNR's system (Specim spectrograph, model V10E ImSpector, with a Hamamatsu CCD ORCA-ERG camera operating in the 400-900 nm range [22]), the data obtained should have been compared with the reference values provided with the chart itself. However, this was not possible since the combination of illuminant[1] and observer[2] used (CIE illuminant D65 and CIE 1964 standard 10° observer, respectively) was in contradiction with the reference data that require the use of the CIE illuminant D50 and CIE 1931 standard 2° observer. Also, the reference data were acquired with a geometry of 8 degrees, while IFAC-CNR data were acquired with the 0°/2x45° observation/illumination geometry. [50, 51]

Looking forward to having the certificated colorimetric values of the chart from the respective producer calculated for the D65 illuminant and 10° observer with 45°/0° geometry, first it was decided to determine the uniformity of the colours in the chart. This was done by comparing the reflectance spectra extracted from 1 mm x 1 mm areas at different places of each coloured patch. Five coloured patches were presented: Blue 13, Green 14, Red 15, Yellow 16 and Magenta 17 (patches are numbered from left to right, and from up to bottom in the ColorChecker chart, Figure 1), which showed a satisfactory degree of uniformity within the respective patch (differences of 0.02±1 in reflectance factor), see examples in Figure 6. Not only that, the spectra from such a small area present fairly good resolution.

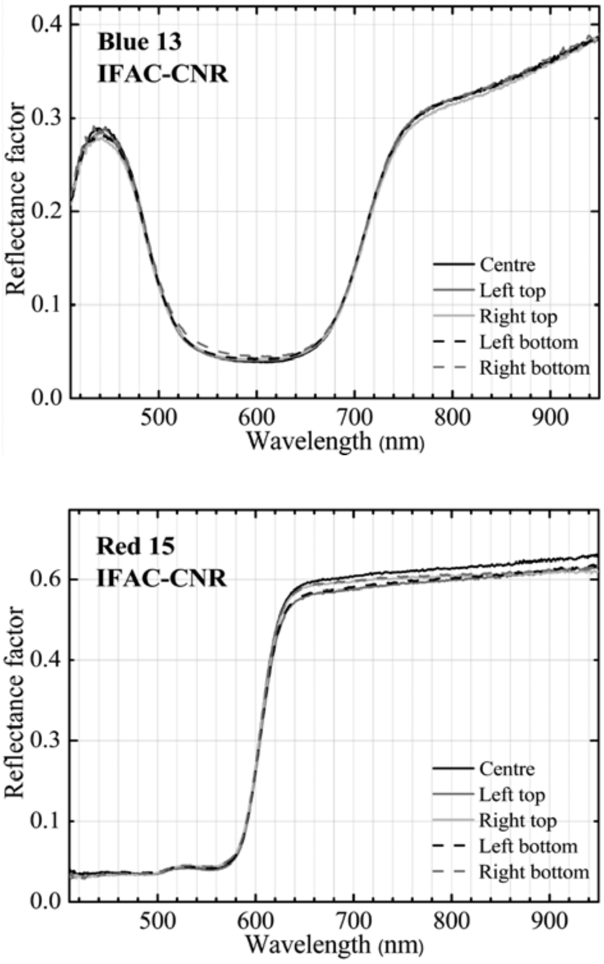

Figure 6. Reflectance spectra from 1 mm x 1 mm areas of coloured patches Blue 13 and Red 15 from the X-Rite® ColorChecker chart extracted from the hyper-spectral file-cube.

Within the same coloured patch, reflectance spectra extracted from centred areas of different size are the same. As a matter of fact, the spectral resolution of spectra extracted from areas of 8 mm x 8 mm and 1 mm x 1mm (high spatial resolution) was proved to be as good as that of spectra extracted from the average areas of 35 mm x 35 mm, showing that there is a good compromise between spectral and spatial resolution for IFAC's system. However, the increase of spatial resolution to 1 pixel had an obvious influence in the spectral resolution. The acquired spectra present more noise probably due to the higher rate of spectral acquisition step and spatial resolution.

Regarding the colorimetric values, they are also constant within the same coloured patch (only some small

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[1] The illuminant represents the light source under which the sample is viewed.

[2] The observer represents how an average person sees colour across the visible spectrum.

variations of 1-2 units in the L*, a* and b* coordinates can be observed), regardless of the area size.

*Round Robin Test 3: SphereOptics Zenith Polymer Wavelength Calibration Standard*

The analysis of the SphereOptics Zenith Polymer Wavelength Calibration Standard was performed in order to assess the calibration of the system through the comparison of the average reflectance spectra with the reference spectrum.

For treatment of the Vis-NIR and NIR file-cubes obtained, the average reflectance spectrum (480 pixels x 480 pixels = 44.7 mm x 44.7 mm in the Vis-NIR and 52.45 mm x 52.45 mm in the NIR), as well as spectra from different areas of smaller size (40 pixels x 40 pixels = 3.7 mm x 3.7 mm in the Vis-NIR, and 15 pixels x 15 pixels = 1.65 mm x 1.65 mm in the NIR) were extracted. The average spectrum was compared with the reference calibration data for peak wavelengths provided with the standard itself. On the other hand, the comparison between the multiple spectra extracted from the smaller areas was carried out to see if there is any variability across the standard surface.

In the Vis-NIR range, there is a 2-3 nm variance in the position of bands, the HIS system presenting wavelengths shifted to lower values. The same was observed in the NIR region, with variances of 3-4 nm, although in this case the HIS system present wavelengths shifted to higher values. Also, the absorbance peaks are more resolved in the reference spectra, mainly at the higher wavelength range. On the other hand, when comparing the reflectance curves acquired in different areas of the standard's surface, there is good uniformity over the whole spectral range analysed (Figure 7).

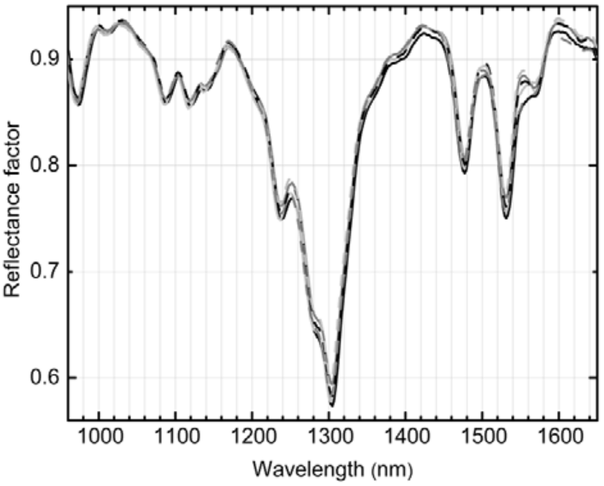

Figure 7. Reflectance spectra of the SphereOptics Zenith Polymer Wavelength Calibration Standard extracted from the NIR hyper-spectral file-cube (comparison of spectra extracted from different areas of 1.65 mm x 1.65 mm).

*Round Robin Test 4: Antique Russian Icon (1899) on tin plate*

For treatment of the Vis-NIR file-cube obtained, the full RGB image was obtained and, from it, reflectance spectra (20 pixels x 20 pixels = 1.9 mm x 1.9 mm) from the different colours were extracted (whenever a colour is present in a lighter and darker hue, data were extracted from both hues).

An RGB image of the Russian icon with very good spatial resolution was obtained with IFAC-CNR's system. Moreover, although the surface of the icon presents specular reflectance from the pseudo-golden areas, this factor was not a difficulty for the acquisition of the file-cube since the geometry of IFAC-CNR's hyper-spectral imaging system is set to avoid specular reflectance from the objects' surface.

From the imaged picture, it was possible to analyse tiny details, selecting areas as small as 1.9 mm x 1.9 mm, which correspond to the best compromise between spatial and spectral resolutions. From areas with this size, the reflectance curves of the different colours were extracted, in order to characterise the coloured materials. Although these materials have not been identified yet, through the observation of the reflectance spectra, it is fairly evident that the primary colours of subtractive colour mixing (cyan, yellow, and magenta) were used to produce the different hues. For example, the green areas were probably obtained by mixing the blue-cyan colour (possibly, Prussian blue) with a yellow dye, and the purple areas were produced by mixing the red dye (most likely, an anthraquinone-based dye) with the blue pigment.

*Round Robin Test 5: Painted test panel – medieval Tuscan technique*

For treatment of the Vis-NIR and NIR file-cubes obtained, reflectance spectra (15 pixels x 15 pixels = 1.4 mm x 1.4 mm in the Vis-NIR and 1.6 mm x 1.6 mm in the NIR) of the various colours and grounds were extracted from the different layers. Due to the non-homogeneity of the coloured paints, spectra were extracted from the top. These were then compared with reflectance spectra acquired with two spectroanalysers with optic fibres (Fibre Optic Reflectance Spectroscopy, FORS) in the 350-2200 nm range, on the same area of analyses, to assess the quality of those obtained with HSI. To study the spatial resolution in the NIR range and the ability to discriminate between the different underdrawings, reconstructed images were obtained at different wavelengths.

Images with very good spatial resolution both in the Vis-NIR and NIR ranges were obtained with IFAC-CNR's system.

From these images, reflectance spectra of the various colours were extracted from the layers with different thickness, from areas with ca. 1.5 mm x 1.5 mm, which was the minimum size possible to obtain a good spectral resolution. With this resolution it was possible to clearly characterise each spectra and correspond them to the pigments used. Reflectance curves from the thinner layers present the higher reflectance factors and, in all cases, the range of wavelength 950-960 nm presents a step that corresponds to the difference in the two spectrometers used, Vis-NIR and NIR that have different sensitivities. When comparing the spectra extracted from the file-cubes with those acquired with FORS, shapes and spectral resolution are very similar, but the reflectance factors are higher with FORS.

Concerning the NIR region, the scan-head provides a very good spatial resolution that allows to discriminate between the various lines made with the different underdrawing materials. Indeed, it was possible to discriminate the areas presenting lines with 1 mm of distance. On the other hand, the visualisation of these underdrawings depended on the transparency of the paint layers. However, the possibility to reconstruct images at different wavelengths allows to go further into the layers and obtain a higher degree of visualisation. For example, for the blue paint layers, it was only possible to clearly observe the underdrawing at ~ 1300 nm, and for the green layer, the legibility of the lines was only fairly possible at ~ 1600 nm.

## 5. RECOMMENDATIONS FOR THE FUTURE WORK OF COSCH

WG1 was expected to conclude PT1 and st1.2 by the end of the second year (2014). St1.1 had to be finalized by the end of the first year (2013). However, the exploration of the limits and advantages of the actual instruments in the visible and near infrared regions has been requiring more time than expected due to the presence of several imaging systems within the WG1 laboratories. Hence, WG1 decided to define a specific Round Robin Test with distinct objects to explore the different spectral imaging systems, identify the impact of each instrumentation on the results obtained, and ensure the usefulness, accuracy, and comparability of the data. This interim report will be completed with the analyses of all the instruments involved in the RRT (see appendix 1).

One or two objects of the RRT will be also investigated by other imaging devices which operate beyond the visible and near infrared (short wave) regions, such as the THz and GHz ranges (st1.2).

At the same time, a glossary/vocabulary will be prepared by WG1 and the conceptual and practical frameworks for multisensory data acquisition, its implementation and evaluation (PT5) will be established.

Finally, WG1 activities will lead to the development of recommendations for solution providers, as well as for end users. These recommendations will facilitate a deeper integration of optical technology into cultural heritage applications through an improved correlation between optical means and requirements (PT6). In addition, the selected user case studies will be successfully completed, analysed and evaluated (M5).

WG1 has to prepare guidelines for the analyses of different materials with different systems written according to the results obtained with each system, for each object, within the RRT. These guidelines will intend to help the COSCH community and the end-users (conservators, archaeologists, etc.) to decide “the best system to use, depending on the object and on the purpose of the analysis”. The idea is to prepare a handbook accessible and attractive to the end-users.

Finally, the information gathered will be used to support COSCH selected case studies, which have to be successfully completed, analysed and evaluated by the end of the Action.
Below, a summary of the actions that had to be considered in order to reach the WG1 project goals at the end of COSCH is presented:

- Creation of a basic dictionary to explain/define technical terminology as basis for any future interdisciplinary project;
- Definition of calibration tools, standard targets and methodological procedures to be followed in the acquisition of multi-band, multi-spectral and hyper-spectral images in the visible and near infrared regions, in order to define the best standardized calibration methodologies in the acquisition and process of the documentation and spectral imaging data;
- Correlation of data obtained from 2/3D and 1D techniques, also at the micro-scale level;
- Provide the WG1 participants with a list of the most relevant reference papers/works in the field;
- Provide more critical approaches to the techniques presented in the talks, showing their advantages and/or disadvantages to the audience;
- Creation of a final CD-ROM with basic information on the proposed/used techniques, also for people without training (end-users).

## 6. PRESENTATIONS

The following presentations were given at the WG1 COSCH meetings:

Mainz (Spring 2013)

- Hyperspectral image capture and analysis of *The Scream* (1893) by Edward Munch. Ferdinand Deger, Sony George, Jon Y. Hardeberg
- Spatial and spectral object reconstruction at CD6. Santiago Royo, Meritxell Vilaseca, Miguel Ares
- Spectral imaging system integrating multiple measurements modes for the quantitative hyperspectral analysis of historical documents. Marvin E. Klein, Roberto Padoan, E. J. van Beek
- Non-scanning Hyperspectral Imaging and Spectral Video Technique for Object Documentation. András Jung
- Real-time evaluation of the photosensitivity of cultural heritage (CH) objects using fiber optics reflection spectrometry (FORS) coupled with accelerated light aging. Julio M. del Hoyo-Meléndez

London (Fall 2013)

- Imaging techniques for cultural heritage objects. Kirk Martinez
- Image capture and rendering by RTI. Lindsay MacDonald
- What makes push-broom hyperspectral imaging advantageous for art applications? Timo Hyvärinen

Cherbourg (Summer 2014)

- Spectral Image Analysis and Visualisation of the Khirbet Queyafa Ostracon. Sony George
- Practice-based comparison of imaging methods for visualization of toolmarks on an Egyptian Scarab. Lindsay MacDonald
- Hyper-Spectral Acquisition on Historically Accurate Reconstructions of Red Organic Lakes. Tatiana Vitorino
- Pigment Mapping of The Scream (1893) Based on Hyperspectral Imaging. Hilda Deborah

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