ANALYSIS AND RESTORATION OF CULTURAL HERITAGE SURFACES AND OBJECTS COSCH WORKING GROUP 4 REPORT ON ACTIVITIES 2012–14

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ABSTRACT: This interim report covers the activities of the Working Group 4 (WG4) 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. In this period, WG4 carried out a critical review of typical applications of spatial and spectral imaging techniques in the conservation field to assess the potential constraints and preconditions imposed by such techniques, as well as evaluate the outputs and analyse the added value of their combined usage. The field covered being substantial, the multidisciplinary team of experts concentrated their efforts on a few materials (mainly metals, graphic documents and paintings). They were particularly interested in checking whether the techniques considered responded to the needs, comparing the performance of one imaging technique to another, and assessing how the characteristics of each material were affecting the acquisition of data. Although essential, the point of view of the end-user is rarely put forward. Therefore the present assessment focused on a few techniques considered by conservation professionals to be easy to use and low cost. Highlight-Reflectance Transformation Imaging (H-RTI) is one of them. It is particularly suitable for flat objects with some reliefs (coins, engravings, mural decorations, etc.). The map obtained is composed of multiple photographs taken from one stationary position, while the surface of the object is illuminated in each shot from different raking light positions. Interactively re-lit, surface details of the object are revealed. Online software enables to easily exchange data between end-users. H-RTI is representative of imaging techniques accessible to end-users, for which guidelines have been developed by imaging experts and which conservation professionals have learned to optimise in order to enlarge the field of application. The objective of the COSCH WG4 in the next months is to extend employ further popular techniques, including photogrammetry, 3D scanning, SLI and MHI.

Foreword

The scientific focus of COSCH is to develop, adapt and standardise the usage of optical, non-contact technologies to record, with high spatial and spectral precision and resolution, the surfaces of heritage objects. The observed data depend on geometrical and physical relationships between the sensor, the surface of artefacts and light source. As a consequence the optimal usage of imaging techniques depends on the characteristics of the object.

Among the objectives of the COSCH Memorandum of Understanding [COSCH MoU, 2012], the most relevant to the Working Group 4 (WG4) are:

- To critically review current integration of state-of-the-art spectral and spatial optical technologies in the conservation field;
- To deepen knowledge of the potential, output, constraints, preconditions and practical aspects of precise spectral and spatial instruments;
- To lay a foundation for an optimised and adapted use of spectral and spatial techniques;
- To develop guidelines for Cultural Heritage authorities;
- To analyse mutual benefits from spectral or spatial sensing techniques and the added value of combined usage.

WG4 work started with identification of typical applications and/or objects to be subject of implementation of optimal processing chains, from data capture, up to the final results, guided by the interdisciplinary expertise available to COSCH. To achieve this primary task (PT4), two sub-tasks (*st*) had been defined in the MoU:

- *st1.1: Identification, structuring and implementation of typical use cases*
- Identifying crucial factors affecting the interaction of surface characteristics of artefacts with the optical radiation and the process of data capture, and establishing a reliable knowledge base.

- *st1.2: Development of guidelines*
- Identifying and defining the impact of the instrumentation on the quality of results.

The field covered being substantial, WG4 started by building its core team of possible contributors. The first Management Committee (MC) meeting in Mainz, held on 26 March 2013, was the occasion to invite some active conservation professionals to discuss some of the COSCH scientific topics. No progress was made within WG4 until the next MC meeting held in London on 23–24 September 2013. In fact it is only after the taskforce meetings in London that WG4 activities could be defined and initiated. It was also during the London meeting that surveys, targeted towards end-users, were initiated with the aim to get a better understanding of how conservation professionals are using optical measurement techniques. It was expected that with this information the Group would define the needs better, and would be better positioned to assess whether they are met by current technologies.

1. INTRODUCTION

During the first year of the Action, WG4 members discussed the COSCH scientific focus and raised specific issues relevant to WG4:

- **Acquisition of data:** creation of reproducible, baseline capture, i.e. resolution for future typical applications for the shape and multispectral measurements;
- **Processing of data:** the reference to original data is essential;
- **Analysis of data:** consideration and recommendation of the required accuracy in regard to the needs of the conservation field; standardised algorithm in conservation, condition monitoring questions;
- **Standardised characterisation**: requirement to monitor artefacts and taking into account the optical properties of the object;
- **Definition of knowledge-base related to the object characterisation:** good knowledge of artefacts required; listing the requirements before the spatial / spectral imaging campaign; the effect of ageing of artefacts on the results; checking of the sensitivity of objects to the light used; use of complementary analytical documentation; ensuring that the image created reflects the accuracy of object characterisation;
- **Visualisation and reproduction issues:** the subjectivity of colours; correct measurement; standardisation of false colours representation; recording of the degradation of the object;
- **Data content:** the inclusion of relevant metadata – objects provenance/history (historical aspects, conservation issues, etc) and technical metadata: acquisition information; assessing whether the acquisition of a large amount of data Is necessary;
- **Data storage, transmission and retrieval:** standardisation of files format; common standards for data storage, open data standards; accessibility and safety issues;
- **Quality evaluation:** evaluation of the comparability with different instruments within the same technique; combination of multiple instrumental analyses; using repeated measurements of similar objects for validation of results;
- **Dissemination:** easy access to data for end-users, production of a “cookbook” compiling data from experienced conservation professionals and case studies.

It is based on these issues that research topics were discussed between participants (see point 3).

2. REVIEW OF EARLIER RESEARCH

The construction of a thorough literature survey to appreciate the application of spatial and spectral imaging to cultural heritage artefacts by conservation professionals and imaging experts is an important outcome of WG4 (see section 3). In WG4 we were particularly interested in the way professionals selected techniques versus artefacts as well as the objectives followed and the possible effects of artefacts characteristics on the results obtained.

WG4 members were asked to select references that were considered the most relevant to them. Obviously this literature survey is not exhaustive: it only covers the field of expertise of the members involved.

Papers comparing the performance of imaging techniques were favoured since it was the occasion to see how one technique adapts better to specific outcomes. As an example Payne compares 3D laser scanning, computer tomography scanning and polynomial texture mapping (PTM) for the improved visualisation of artefacts surfaces [Payne, 2012]. She describes that important issues to consider are: the light angle to take the picture (PTM), physical stability of artefacts – inappropriate to fluffy materials: feathers, fur associated to metal (laser scanning), distance object/laser (laser scanning), size of the object, gloss level (inappropriate for highly specular surfaces).

Imaging techniques have often been applied on metals. Coins have been studied with Highlight-Reflectance

Transformation Imaging (H-RTI) [Mudge et al, 2012] for improved visualisation as well as condition survey. The 3D modelling of metal sculptures have been investigated at several occasions using laser scanning [Beentjes et al., 2010; Wilson et al., 2010; Bellendorf, 2007] or structured light imaging (SLI) [Rocchini et al., 2001]. It has been shown that the presence of corrosion products, the deformation of the metal surface, the reflectivity of the metal surface as well as the volume and the depth of reliefs are affecting the results.

H-RTI has been tested as well on paintings [Mudge, M. et al. 2010] with more traditional IR reflectography (near IR, short wave IR) [Ibarra-Castanedo et al. 2011] and multi-hyperspectral imaging (MHI) [Cotte, P. 2010; Picollo et al. 2007]. Once again the depth of reliefs (brush strokes application), 3D defects (craquelure, cracks) and glossy surfaces are affecting the quality of the results.

Stones (steles [Mudge et al. 2011]), glass (enamels) and prints [Mudge et al., 2010] investigated by using H-RTI for improved visualisation and condition survey are other typical case studies. In the latter case scraped letters and ink deterioration are effecting the results.

Apart from painting, MHI is often applied on prints [Klein, 2007; France et al., 2011] and parchments [Bearman et al., 2009] for documentation, condition survey and conservation monitoring. Ink deterioration and contrast ratio of reflectance levels of the materials concerned affect the results.

Structure from motion (SfM) gives good results on wood (sculpture [Samaan et al., M. 2013]) for data acquisition and processing improvements and on stone for 3D modelling [Bryan et al., 2013].

These are just a few examples showing that the choice of imaging technique depends strongly on the characteristics of the materials to be examined.

While being useful for an overview of possible application of imaging techniques to document cultural heritage artefacts, and the way these artefacts are or not suited to applications of these techniques, this compilation was of little help in establishing their actual use by conservation professionals. Therefore we decided to carry out a more thorough survey on a few techniques selected either because conservation professionals are praising them, or WG4 members have expertise of them.

H-RTI is certainly one of the most fashionable tools among innovative imaging techniques applied by conservation professionals. Our literature review on this technique aimed at seeing how the scientific knowledge has been transferred to end-users and how the end-users adapt the technique to the specific characteristics of the artefacts under examination. The following points have been covered:

- The principle of the technique,
- A compilation of referenced case studies with the justification of use of H-RTI versus other imaging techniques (often referring to the characteristics of the objects), the equipment and conditions used and a critical review of end-users,
- Illustrations of some applications,
- Development of guidelines with illustration of recommended setups and corresponding references,
- Teams currently active in H-RTI.

The outcomes of this work are presented in Appendix 1. This survey has been reviewed by experts in H-RTI (either imaging or cultural heritage professionals). Subsequently to receiving their feedback, the information will be shared with members of other COSCH WG to see whether all important H-RTI parameters have been taken into account.

Similar work is planned in the near future on the following techniques:

- Photogrammetry (collaborative work by J. Guery, A. Pamart, S. Wefers, A. Mathys and V. Moitinho),
- 3D scanning (collaborative work by F. Laroche, S. Wefers, A. Mathys and V. Moitinho),
- SLI (E. Bunsch),
- MHI (M. Picollo and R. Padoan)

E. Kouloumpi, S. Röhrs and B. Constantinescu will review the work carried out.

We expect, through these different surveys, to be able to compile the knowledge on the influence of the characteristics of artefacts on the quality of the results obtained, contributed by both the conservation and imaging techniques experts.

3. DISCUSSION OF THE CHOSEN APPROACHES AND METHODS

Research questions within WG4 were raised during COSCH taskforce meetings. The participants of each meeting were coming from different backgrounds (physicists, conservation scientists, engineers, conservators, archaeologists, a manager of a CH site) and were either developers of optical techniques or end-users. They therefore constituted a team representative of the multidisciplinary approach of the COSCH Action. Some, but not all, participants attended both meetings.

WG4 participants raised a number of questions that required some thought. The questions are listed in the table below and put in relation to COSCH scientific focus and primary tasks mentioned in section 1, as well as COSCH primary tasks.

Topics	Objectives	Questions	COSCH scientific focus	Primary tasks covered
Limits of the technology versus the nature of materials	- Adapting the technique to the surface appearance - Monitoring artefacts (slight change, oxidation processes)	- Effect of coatings, over-paintings and surface shine? - Precision / accuracy level required to see a difference during a monitoring exercise?	Data acquisition	PT1
Adapting the technology to the needs, **whatever the material considered**	- Condition survey of altered materials (colours as diagnostic tools) - Material analysis - Conservation treatment - Reproduction - Virtual engineering - Dissemination	- Precision / accuracy level? - OK for visible colours but what about other spectral information for diagnosis? - 3D scanning of the oxidation of a varnish? - 3D scanning to assess a varnish removal, consolidation treatment on paintings? - Collaboration with WGs1 and 2? - Standardised measurements for monitoring? Taking into account the size of the artefact	Acquisition, processing, analysis, standardised characterisation, visualisation and reproduction, data storage, quality evaluation, dissemination	PT2, PT6 and PT1
Characterisation of digitalisation approaches	- Spatial resolution - Spectral resolution - Accuracy of the colour values (L*a*b*) / accuracy of the spectral data - Accuracy spatial digital model/data - Workflow / automation of digitalisation process	- Do we need combined data sets (spatial and spectral): the case of Vis-NIR on 2D surfaces? - What are the potential advantages? - What technical and other problems have to be solved? - What could typical application scenarios look like? - Would an exchange with WG 1 and 2 be useful?	Knowledge base related to object characterisation and standardised characterisation	
Data	- Quantity - Storage - Future compatibility	- Estimation of the volume - Safe storage - Conversion into other formats - Metadata: technical data and additional information on the object.	Data storage, transmission and retrieval addressed to WG1 and WG2.	PT4, PT6
Cost of digitalisation	Depends on the type of objects: might be easier for archival 2D artefacts than museum 3D objects	Estimation can be carried out if standardisation is available.	Dissemination	PT6

These research topics were further discussed by WG4 members:

- Limits of the technology vs the nature of materials

- Spectral imaging: comparison of data-cubes during monitoring is not always possible due to the instability of materials and technology. Not all materials are suitable for applications of these techniques: simple foils – yes, bonded materials – not.
- 3D scanning of very soft, waterlogged materials or structures that are inaccessible.
- The risk of the 3D scanning that might lead to a low cost outcome that could eventually replace an expensive conservation treatment of an original object.
- Accuracy of the changes observed, even small changes, during the monitoring process and the fact that they are due to the ageing of artefacts. Data showing ageing trends should be accessible. Here the reference measurements are essential to make sure that the data collected are correct.

- Adapting the technology to the needs, irrespectively of the material under examination

- *Condition survey of altered materials (colours/shape as diagnostic tools)*
- Integrating spatial and spectral techniques within the group of other tools, easily accessible to conservation professionals, and while documenting artefacts within their environment.
- Adapting the technique according to the budget available, the level of precision required by conservation professionals (often lower than what the techniques offer).

- Guiding the conservator on how to properly use imaging techniques, from the basic to the most sophisticated techniques.
- Monitoring the artefacts in an easy way: a portable tool with simplified settings and easy to use software.
- Controlling the artefacts on loan during transport, exhibition and after their return to the lending institution.
- Combining, if needed, the shape / spectral imaging.
- Setting up an automated, visualisation protocol for large collections.

- *Use of imaging techniques for material analysis*
- Tools already exist.
- But the way these tools should be used properly should be explained (see COSCH^{KR}).

- *Use to monitor conservation treatment (a very specific issue)*

- *Production of reproductions*
- Even the best results do not replace originals so far.
- 3D printed copies are interesting for educational purposes.
- Material copies, made by using traditional manufacturing techniques and the same materials, are often better than 3D printed copies.
- 3D reproductions of industrial heritage objects are useful to understand how they were operated. In that case the 3D print should be fully functional; the original socio-economical contexts should not be neglected.

- Characterisation of digitalisation approaches

The choice of the instruments is made after the definition of the level of resolution / precision required.

- *Level of resolution and precision*
- Depends on the time and budget availableDepends on the needs of the end-user
- All parts of the artefact do not require the same level of resolution (number of spectral bands)

- *Time required for digitalisation*
- To be considered in parallel to the required precision
- Will have an impact on the cost of digitisation.

- Data collection

- Estimation of the volume of data, including metadata (technical data on the technologies and additional information on the object). IT departments in institutions have to be aware of the space on servers requested for the documentation of artefacts using spatial and spectral techniques.
- Safe storage. Data stored on private databases might be lost.
- Conversion in other formats (compatibility). A few decades are enough to loose the technologies used at that time to record and read spectral or spatial data.

- Cost of digitalisation

- Estimation of costs might be possible if documentation is carried out in a standardised way.
- Costs are lower for 2D objects than 3D objects.

Since some aspects of the research topics discussed between the participants could be covered through a literature review, we asked the participants to contribute to the following reviews that were intended to cover sub-task st1.1:

1. A review of published applications of optical techniques covered by COSCH on Cultural Heritage artefacts or sites. As said before, the **objectives** of the authors and the way the characteristics of the artefacts / sites under investigation affect the results obtained (see section 2) were of particular interest to us.
2. A review of the current and future needs of the conservation field towards optical measurement techniques. Some are already known (see above) but others are not.

It was expected that these reviews would allow us to provide guidelines on the proper use of imaging techniques (sub-task st.4.2 – *development of guidelines*). The work carried out on H-RTI (see section 2) was encouraging us in that direction.

In addition to its particular tasks WG4 got committed to the development of COSCH^{KR} introduced to the members during the taskforce meeting in Amsterdam. The following table indicates the issues raised by WG4 members.

Questions	**Comments**	**Possible response(s)**
How end-users should approach the COSCH^{KR} App?	Questions articulated by the end-users are often vague. The end-users may need to clarify their questions before questioning the COSCH^{KR} App.	- These questions often relate to dating, technology or conservation issues. - The COSCH^{KR} App could be that clarifying tool: it would guide those professionals that have no or only basic knowledge, to approach experts for an additional question. - Could be considered as a FAQ platform.
Will the expertise provided by the COSCH^{KR} App match the end-users needs?	Difficult for scientists from WG1 and 2 to anticipate the type of questions coming from the conservation professionals	- WG4 members could represent the conservation professionals and raise points that would match the expertise provided by WG1 and WG2 scientists. Associations of conservators in the different countries represented within COSCH could also be contacted.

		For example, CESMAR7 or IGIIC in Italy, VDR in Germany, SKR in Switzerland and the Institute of Conservation (ICON) in the United Kingdom. - Would make more sense to ask the participants of earlier meetings for the feedback, than to organise a dedicated meeting with the end-users in one or several countries (too expensive) and perhaps not so productive.
Type and level of the information provided by the COSCH^{KR} App?	Adapting the app to the experience and individual requirements of the end-users of techniques covered by COSCH.	- Educational tool. - No definitive answer would be provided, but an approximate approach to the documentation protocol to be followed. - Recommendations should be provided when using certain techniques for a specific application. - Other techniques than just spatial and spectral techniques should be covered: links to these other techniques would be suggested, details of the experts in the field would be proposed. - Information should be regularly updated: the COSCH^{KR} App has to be enriched with new information (case studies, publications) beyond the duration of the project.
Should the COSCH^{KR} App address the needs of different audiences? Archaeologists (more knowledgeable about 3D scanning), conservators or curators (more familiar with VIS, UV and IR photographs).	Categorising the answers	Should be more adapted to help with solving problems specific to a particular field, or the object, rather than to aim at specific audiences. The COSCH^{KR} App would direct the end-user to the relevant professionals (conservators, curators, archaeologists) and subsequently lead to information on a particular topic (dating, technology and conservation issues / characteristics of materials and operability) and finally, to the best suited imaging techniques.
Efficiency of the COSCH^{KR} App?	Evaluation of the information	- During the construction of the COSCH^{KR} App. - Process to carry out once the COSCH^{KR} App is completed and accessible to end-users. - Final use?
How to make the COSCH^{KR} App visible to the conservation community?	Dissemination of the tool.	- Each COSCH member should promote the tool within his own network. - Conference presentations.

The WG4 also produced, at the request of the COSCH^{KR} group, a draft questionnaire for the COSCH^{KR}, consisting of the following questions:

- Which spatial and spectral technique/s was/were chosen to document the cultural heritage object or site?
- Name of the cultural heritage object or site?
- What was the aim of documentation? Multiple answers possible (visualisation, condition survey, material analysis (using spectral techniques), reproduction (e.g. printout), dissemination.
- What is the level of resolution / uncertainty required? (Might only be answered by technicians.)
- If you did carry out spectral analyses, what wavelength range did you choose?
- What is the size of the documented cultural heritage object or site (length, width, height in mm, cm, m; choose the appropriate scale unit. When documenting only part of the object, please provide the size of the fragment?
- What is the shape of the cultural heritage object or site (e.g. round, flat, building with narrow parts etc.)?
- What is the appearance of the cultural heritage object surface (glossy, homogeneous or heterogeneous: same colour with various tints or multicolour, etc.)?
- Is your cultural heritage object static or movable? Can it be transported?
- What is the budget allocated to this documentation project?
- What is the timescale available for the documentation project?
- What are the reasons behind the selection of the technique/s?
- Did the spatial and spectral technique/s fulfilled the initial needs?

The WG4 members were active in suggesting the case studies to test the validity of the COSCH^{KR} questionnaire:

- Eryk Bunsch*: WPR Kultura+ Wilanowskie muzeum cyfrowe+ (III etap)*
- Christian Degrigny: *Germolles wall paintings*
- Eleni Kouloumpi: *Virgin and Child (Western)*

- Marcello Picollo: *Hyper-spectral Imaging Data acquired on the San Martino a Mensola "Annuciazione" panel painting*
- Christine Riquier-Bouclet: *Photogrammetry : 3D model used as a tool included in the chain of acts of conservation.*

6. SELECTED PRESENTATIONS

The following presentations were given in the WG4 COSCH meetings:

MC - Mainz (spring 2013)

- *Colour and Scale: Colour Measurement on Small and Large Museum Objects*, Stefan Röhrs
- *Hyperspectral Imaging for the Standardization of Documents Monitoring at the Nationaal Archief (The Netherlands)*, Roberto Padoan
- *A Systematic Non-invasive Optical Investigation of Wall Paintings at a UNESCO World Heritage Site*, Haida Liang
- *Multi-scale and 3D Imaging Spectroscopies of Finishes Coating Historical Musical Instruments: Recent Developments and Trends*, Jean-Philippe Echard, Camille Simon-Chane, Stéphane Vaiedelich

WG4 taskforce meeting - Amsterdam (February 2014)

- *An overview of different imaging techniques used to document heritage* artefacts, B. Constantinescu
- *Physicochemical study & NDT of artworks; from theory to museum practice,* E. Kouloumpi
- *From heritage knowledge capitalization to cultural mediation thanks to augmented digital technologies*, Florent Laroche
- *Fiber Optic Reflectance Spectroscopy (FORS) and Hyper-spectral Imaging (HSI) Techniques applied to the analysis of polychrome surfaces*, Marcello Picollo
- *Photogrammetry tool for archaeological objects conservation*, Christine Riquier-Bouclet

WG4 taskforce meeting - Berlin (summer 2014)

- *2D/3D - digital reproductions and the National Museum Berlin*, Andreas Bienert
- *Scanning for 3D Reproduktion*, Samuel Jerichow & Thomas Schelper
- *Multispectral Imaging at Rathgen Research Laboratory*, Ellen Egel

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