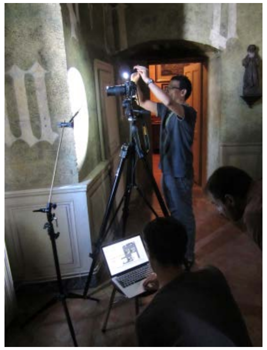
ANALYSIS AND RESTORATION OF CULTURAL HERITAGE SURFACES AND OBJECTS
COSCH WORKING GROUP 4
REPORT ON ACTIVITIES 2012–14
Appendix 1

Christian Degrigny [a],*, Eryk Bunsch [b]

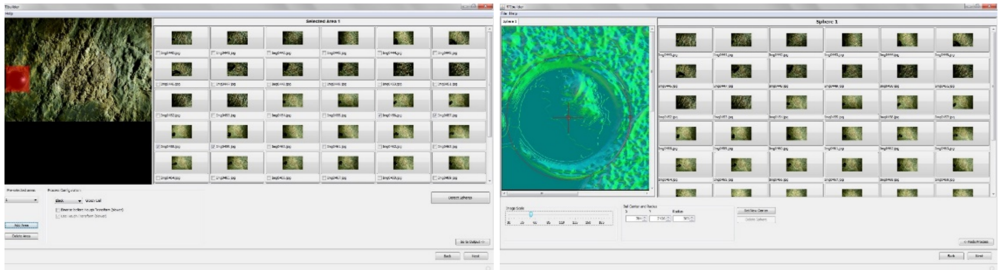
[a],* Haute Ecole Arc Conservation-restauration, Neuchâtel, Switzerland – Christian.Degrigny@he-arc.ch
[b] 3D Documentation Laboratory, Museum of King Jan III Palace in Wilanow, Warsaw, Poland – jerzywart@yahoo.de

Highlight–Reflectance Transformation Imaging (H-RTI) for Cultural Heritage Applications



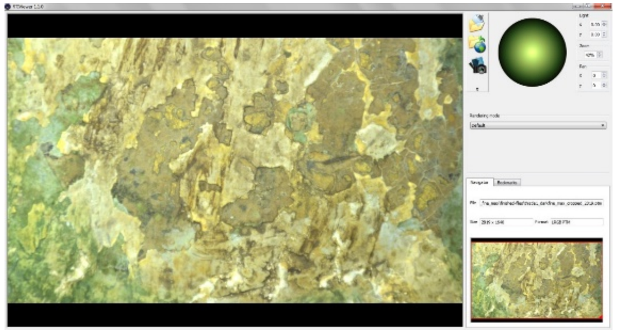
Lighting setup

Reflectance Transformation imaging (RTI) is a term used to describe a broad family of image-based recording methods in which information about surface reflectance is captured per pixel. A polynomial texture map (PTM) is composed of multiple photographs taken from one stationary position while the surface of the object is illuminated from different raking light positions in each shot. Using a specially developed algorithm, a computer program synthesises the images, compiling all information into one file. Dedicated viewing software enables the object to be interactively re-lit, revealing surface detail (Duffy 2013).



Data processing

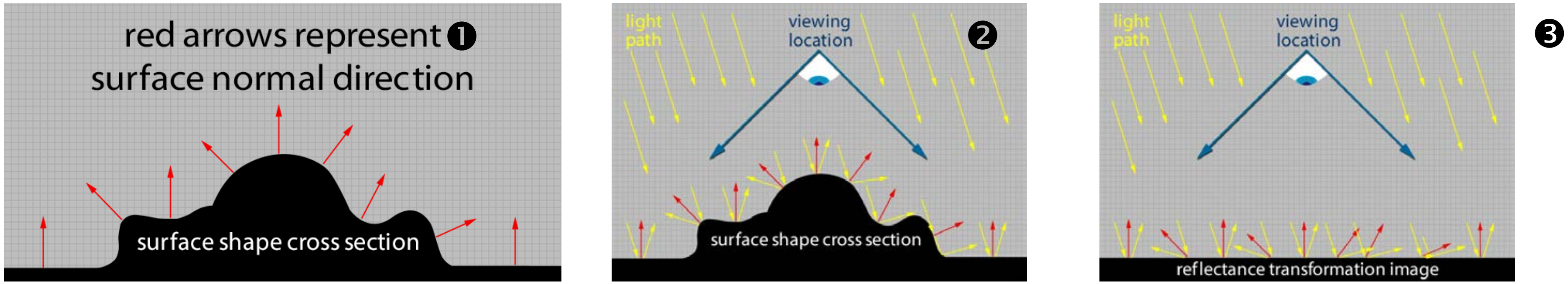
Highlight-RTI (H-RTI) involves the user moving a handheld light source around the object to photograph and recover the lighting direction from the specular highlights produced on one or two reflective targets included in the field of view captured by the camera. This capture method is flexible and a low-cost.



Visualisation. Highlight-Reflectance Transformation Imaging from lighting setup to visualization through data processing © C. Degrigny.

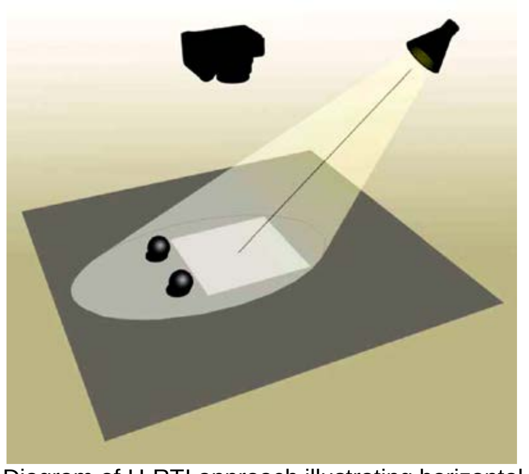
Principle

The following figures show how RTI technology works:



❶ Mathematically, the direction that is perpendicular to the surface at any given location is represented by a vector (direction) called a *normal*. Technically it is a vector that is perpendicular to the tangent plane at any point on the surface. ❷ Light bounces off of surfaces such that the incident angle of the light and the reflected angle of the light are equal angles to the surface normal. Since the camera is in a fixed position, and we know where the light is coming from in each image, and because we sample from a variety of light positions, RTI software can calculate the surface normal per pixel in the image. ❸ The mathematical description of the normal is saved per pixel, along with the RGB (red-green-blue) colour information of a regular photograph. This ability to record efficiently the colour and true 3D shape information is the source of RTI's documentary power. The figure shows the reflection information captured in the RTI (from CHI - http://culturalheritageimaging.org/Technologies/RTI/. Accessed 12.02.2015).

The way the operator proceeds to capture photographs is indicated in the two diagrams below:



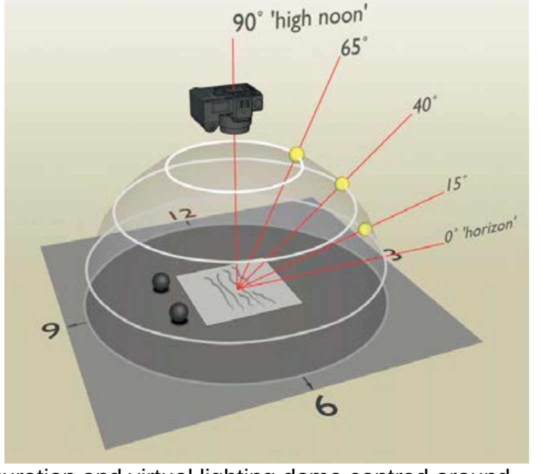


Diagram of H-RTI approach illustrating horizontal capture configuration and virtual lighting dome centred around virtual clock – note lighting positions at 15°, 40° and 65° above 'horizon' (0°) © English Heritage; drawn by John Vallender.

Benefits

- Non-invasive,
- 2D recording technique but providing 2½D information on 3D objects,
- Cost-effective (inexpensive tool kit and freely available software). High level of details can be obtained when using expensive, high-resolution camera and high-quality lenses; team involved: 2 (camera and light source),
- Flexible technique: can be used on remote sites and horizontal/vertical surfaces,
- Final document can be shared between experts for discussion.

Limitations

- Might be time consuming,
- No quantitative metric data (in comparison to laser scanning or photogrammetry),
- Only surface texture is captured (to see below overlying materials, multispectral imaging in UV and IR radiations is needed),
- Resolution is optimised if the object has a size inferior to 2m in diameter,
- The quality of the final document depends on the images capturing process.

Applications

- Surface texture and detail,

- Documentation of the condition of an object at the time of recording (useful for monitoring artefacts).

Tool kit

- Camera: must be able to photograph in RAW, needs a manual setting in which aperture and exposure can be manually controlled, with remote capability (to avoid moving the camera), tightly fixed in place, with normal lens, with large memory (24 to 60 shots are required).
- Tripod: stable. Additional tripods might be required to secure the reflective targets in a vertical position.
- Reflective targets: glossy, spherical, size depends on the size of the object being photographed, must remain stationary throughout the recording phase, two targets might be required in some cases.
- Light source: enough aperture to create distinct reflectance points on the targets, with broad-spectrum light for good colour rendering, can be continuous or flash (to synchronise with the camera).
- String: used as a flexible aid to determine the distance that the light should be separated from the surface of the object and to recreate an ideal virtual dome using three angles (0°, 30° and 60°).

LITERATURE REVIEW

The following table gives some published examples of use of RTI and H-RTI in cultural heritage applications. The justification of use of RTI is provided and operating conditions are given when available (including equipment). The outcomes of using RTI and recommendations are summarised in the "Critical review" column.

Case study	Object	Justification for use	Equipment / parameters	Conditions	Critical review
1	**Paintings (including mock-ups) surface**, National gallery London, UK: max. 40 x 45cm. Padfield 2005.	Observation under raking light is difficult to reproduce and only a few spots observed. SLI & laser scanning: too expensive and files too big. PTM tested as an alternative to investigate paintings and monitor them.	Prototype lighting dome with 24 tungsten halogen lamps. Camera: Sony DCS-F828. PTM software: HP laboratories. 24-50 images taken. Reference material: matt white Teflon sheet.	Indoor + acquisition time: 10 min., exposure 800lux.h.	<u>Outcomes</u>: ability of the technique to detect and display features including impasto, cracks, general and point surface deformations, canvas weave, wood grain and even *pentimenti*.
2	**Coins from the Hospice of the Grand St. Bernard**, CH: few	PTM acquisition: dynamic process of intentional viewing, exploring, in an intuitive manner	Camera: Canon 1Ds (11mpx) with 100mm micro lens triggered remotely by computer + fibre optic light + coins on a calibrated Kodak 18% grey card.	Indoor + acquisition time 30 min. per side of a coin.	<u>Outcomes</u>: adapted to highly specular materials such as gold using specular enhancement. More contrast with diffusion gain enhancement.

	cms. Mudge 2005.	A far richer data set.			
3	**Rock art,** Portugal: 50x70cm. Mudge 2006.	New H-RTI in replacement to hand-drawn graphics and conventional photography or laser acquisition / photogrammetry requiring specific skills and even PTM acquisition: less expensive, portable, easy to use.	Camera: SLR digital camera with neutral density filters + light-reducing neutral density filters + computer with remote camera control software + tripods + radio flash trigger + 1 to 1/32 power adjustable 320watt second flash with battery pack + black ball + measuring tape + retractable surveyors plumb-bob string + intensity-adjustable continuous light if needed.	Outdoor + acquisition time 105min. (2 persons)	<u>Recommendations</u>: aperture: f/11 to f/16; shutter speed: 1/180th of a second. <u>Outcomes</u>: works well. Learning process: less than 1 day.
4	**Large objects**: 0.6-0.7x0.5-0.6m to 2x1m. Dellepiane 2006.	High quality PTM to medium-large objects. Alternative to expensive 3d scanning.	Camera: Canon Digital (8mpx) + a 1000W halogen floodlight + a tripod and a boom stand. References placed on the floor. The position of the light is changed for every photo of the set.	Outdoor?	<u>Outcomes</u>: detailed representations with a low cost and simple acquisition system.
5	**Glass tesserae**, Angeloktisti Church at Kiti, Cyprus: few cms to 1m. Zanyi 2007.	H-RTI adapted to such shiny materials.	Camera: dual camera setup with a Canon 5D and a Canon 1DS (11mpx), both with 50mm fixed lenses + radio triggers to fire the cameras simultaneously + black billiard ball placed on a boom arm, attached to a ball head on a tripod + 250watt xenon arc lamp light source + PMMA acrylic cable acting as a band pass filter, excluding both UV and IR light and passing only visible wavelengths between 400 and 750nm. Software: CHI RTIbuilder and Viewer.	Indoor + 79 light positions were acquired (3 persons).	<u>Outcomes</u>: possibility of exploring in a controlled manner what sort of perceptual effects are possible from glass tesserae depending on the angle of the light.
6	**Hellenistic stelai**, Chersonesos museum Ukraine: max.1m. Rabinowitz 2009.	Sustainable, locally-directed program of heritage imaging and documentation at a site without independent access to complex and expensive digital resources	Camera: Canon EOS 450 digital SLR with 50 and 100mm fixed lenses + a set of Kenko extension tubes + a monopod on which was mounted an Elinchrome studio light synced to the camera + a Gitzo G1320 tripod for the camera + two light stands with umbrella brackets (for	Indoor + trainees: academic course.	<u>Outcomes</u>: offer the potential to enhance research and scholarly communication, especially for those objects whose interpretation depends on a close reading of surface detail.

			black billiard balls); and two fixed studio lights. Software: CHI RTIbuilder and Viewer.		
7	**Outdoor monuments at the Guild of All** **Art** in Scarborough**,** Canada: several meters. Gabov 2011.	Documenting and monitoring of outdoor planar monument with RTI.	Camera : Nikon D700 and D300s + 50mm or equivalent lenses + flash AlienBees ® B1600 (640 true watt/seconds of power) with 6 f-stops and a maximum 2-seconds of recycle (Paul C. Buff Inc., Nashville) + battery: Vagabond II ® Portable Power System + PocketWizard ® series of flash remotes + wireless shutter remote + string (coloured nylon mason's line) + sturdy aluminium tripod + 2 snooker balls. Software: CHI RTIbuilder and Viewer.	Outdoor + students: academic work.	<u>Recommendations</u>: black snookers perform better than red ones (automatic detection with software). More expensive than in Duffy 2013: 3000$. Use a spirit-level to align camera for monitoring measurements. Exposure: 1/320s. Addition of a rod in the flash umbrella attached to the string to make sure that the flash is oriented towards the object. String removed at the time of the shot. Specular enhancement can be used to monitor damage with time. Surface normal visualization: to see which areas of the RTI can be used: should be blue. <u>Outcomes</u>: works well but need to develop quantitative standards for measuring the quality of a highlight-based RTI capture.
8	**RTIS-ADS**, archaeological objects, UK: all sizes from 0.3mm to meters. Earl 2011.	Testing a range of techniques (lighting rigs or highlight) for gathering and processing RTI data: establishing Southampton and Oxford as hubs for RTI research in UK + repository for RTI data.	Camera: Nikon D3X DSLR (24.5mpx with a 14 bit 35.9 by 24.0mm FX CMOS sensor - resulting images are 6048x4032pixels) + Range of lenses employed: 35mm, 50mm and 105mm macros. Lighting systems: dome and mini-dome. Highlight RTI kit. Software: CHI RTIbuilder and Viewer.	Indoor: time depends on the artefact.	<u>Outcomes</u>: development of policies and methods for managing and integrating large quantities of data.
9	**Egyptian material culture,** Ashmolean Museum, British Museum, and World Museum in Liverpool: all sizes. Piquette	Testing two RTI techniques: dome or H-RTI.	1m diameter dome assembled in Oxford: in 4 parts which makes it more transportable. 76 photographs can be taken from different angles on an object not larger than 17x17cm. Use of RTI Viewer to see the pictures. H-RTI for larger objects or objects with logistical challenges: not easily	Indoor: work carried out within the RTISAD project (see above)	<u>Outcomes</u>: legibility of the difficulty to work the materials (clay, bone, ivory, metal, stone, wood) as well as the way to work them (evidence for direction, pressure and force that reveal the skill and habit of an artisan). Other applications: documenting other material culture, from skeletal or botanical evidence to lithics and ceramics.

	2011.		reachable.		
10	**Clay funerary cone,** UCL Petrie Museum: ∅ 10cm, characters protrude to a height of 1mm. MacDonald 2011.	Comparison for the rendering between 3D digital representation with point clouds from 3D laser scanner, RTI and photometric stereo.	RTI: dome of diameter 1.03m with 64 flash lights in 5 tiers. Camera: Nikon D200. Max. size of the object: 30cm.	Indoor. No other mention.	Outcomes as regards RTI: visualisation through interactive viewing tools; better discernment of surface detail than direct physical examination; no data loss caused by shadows and specular highlights; simple image processing pipeline; higher resolution on the object surface than obtainable with 3D scanners. From the 3 techniques studied, photometric stereo gives the best results.
11	**Application of imaging techniques in Conservation,** Payne 2012.	PTM versus 3D laser scanning and CT scanning. Resolution provided by 3D laser scanning is not typically as good as that from ordinary digital photography, as used to construct PTMs. PTM can be more suitable for documenting fine surface detail than laser scanning.	No information. General statements.	Not mentioned.	Recommendations: Application of diffuse gain and specular enhancement in RTI enabled surface features to be accentuated to a greater degree than possible with raking light photography. Risks? Camera flash constitutes a negligible risk for most materials. Outcomes: More easily repeatable than raking light photographs. Appropriateness of the current role of such techniques within conservation (use, advantages and limits, preservation and accessibility of objects).
12	**Archaeological worked antler** (Star Carr, UK): 15×80mm. Duffy 2013.	RTI is non-invasive. Laser scan: not satisfactory because of the nature of the material (dark and porous).	Camera: Nikon D60 (10.2mpx) + compatible wireless remote + Lowel Pro iD lamp (continuous, dimmable and battery operated) + 2 black snooker balls + 18% greyscale card. Software: CHI RTIbuilder and Viewer.	Indoor + acquisition time: 1 afternoon with 2 persons for 3 antler points, front / back.	Recommendations: the distance of the light x3-4 the diameter of object was still too short: too bright pictures. Reflective balls available (snooker balls) not adapted: too big. Outcomes: tool marks could be separated visually from abrasion marks.
13	**Prehistoric rock art** at Roughting Linn, Northumberland, UK: largest	RTI enables to see the subtle surface details. Photogrammetry / rubbing: not interactive enough. Remote location.	Camera: Canon 22mpx EOS-1Ds Mark III + compatible wireless remote-controlled flash + cable-release remote + neutral density filters of varying intensities + Manfroto tripod + 2 black	Outdoor (daylight + uneven terrain + wind + rain) + acquisition time 1 afternoon with 2	Recommendations: difficult to see the reflectance on the surface of the rock and assure that the light was illuminating the correct section of the rock panel: more photographs were captured than is typically necessary (approx. 50–60 shots). Self-

	decorated rock in North UK, 20×15m. Duffy 2010 & 2013.		snooker balls + scale ruler + string mounted on PVC pipe and 18% greyscale card. Equipment was self-powered and properly charged. Software: CHI RTIbuilder and Viewer.	persons for 2 rock art panels (0.75x0.75m)	powered, high-intensity continuous light source would have been more appropriate. <u>Outcomes</u>: feasibility of using RTI technology at remote rock art sites in England in daytime lighting.
14	**Ughtasar rock art site**, Armenia: anthropomorphic figures, ∅ 0.5–0.75m. Duffy 2013.	RTI complements specialised photography, photogrammetry. Remote location + inexpensive tool kit.	Camera: Nikon D60 (10.2mpx) + compatible wireless remote + Lowel Pro iD lamp (continuous, dimmable and battery operated) + neutral density filters of varying intensities + 2 black snooker balls + Benbo tripod + supplemental lighting. Software: CHI RTIbuilder and Viewer.	Outdoor during nights (low T, wind, wildlife and uneven terrain) + acquisition time 6 nights with 3-4 persons, more than 20 panels.	<u>Recommendations</u>: continuous light source was used and proved easier to control than flash lighting. All equipment, including the lamp used for PTM photography, was charged using a makeshift solar power system. <u>Outcomes</u>: H-RTI highlights aspects of the motifs that had not been previously identified. Future plans: study the deterioration of the ancient motifs.
15	**Roman painted statue head** from Herculaneum, I: 380mm tall. Duffy 2013.	Use physically accurate 3D computer graphics with RTI to virtually reconstruct examples of Roman polychrome statuary from Herculaneum. Other tools: laser scanning and conventional digital photography.	Dome-based RTI system. Cameras: Nikon D300 and a Nikon D3X with a 200mm zoom lens and several fixed lenses (combination enabled to capture high-resolution images and close-up RTIs). Software: CHI RTIbuilder and Viewer.	Indoor + acquisition time: 4hours (2 persons).	<u>Outcomes</u>: generate ‘normal’ maps, providing an extremely detailed 3D record of the surface of the object. Virtual record of the object to consult when the real object is unavailable: adapted to collaborative work with colleagues at multiple institutions. Challenges in recording an object with this much depth (selecting which areas of the image were to be in focus during each capture).
16	**Microscopic RTI of gilded silver discs** from the Derveni tombs, Macedonia, Greece: diameter 36mm. Duffy 2013.	RTI minimises the amount of physical handling and thus limits damage. Replacing the traditional insufficient documentation, mainly hand-drawings and photographs. Affordable cost.	Microscope equipped with a camera + pen light + straight sewing pins (20–50mm) with ball-shaped, glossy, plastic heads(∅ 1–4mm), either red or black, and sharp point + plastazote foam sheet (material commonly used in museums for storage of fragile items) + modelling clay or plasticine. Cardboard sheets used to block the light from other sources. Software: CHI RTIbuilder and Viewer.	Indoor.	<u>Recommendations</u>: the millimetre-level accuracy in light-to subject distance is extremely difficult to achieve (light-to-subject distance should be 4× the diameter of the subject). A rotation ring would speed data acquisition and increase the quality of captured data. The microscope arms block some of the light from specific directions. Alternative types of microscope should be considered. Micro-dome lighting would better address the problems listed above. <u>Outcomes</u>: valuable tool for documentation and condition state recording + morphological analysis of depositions: contribution to interventions.
17	**Paintings and paper documents (36**	Exploration of RTI by conservators: cheap tool to for direct examination of	No information.	Indoor.	<u>Outcomes</u>: advanced form of raking light, RTI combines the same colour quality and resolution found in digital photographs with data of light

	objects), Universitat Politécnica de Valencia Conservation Department (UPV) and Valencia Institute of Conservation (IVCR): not larger than 1.5m. Tamayo et al. 2014.	the physical artefact, useful for identifying how the object was manufactured Techniques, surface condition, and assess textural changes produced by conservation treatments.	Software: CHI RTIbuilder and Viewer.		interaction on surface forms, as well as knowledge of human perception to create images that precisely represent 3D shape characteristics. Identification of manufacturing techniques and assessments of surface condition using simple photographic equipment and open-source software, making it an accessible and affordable method to be adopted by conservators and researchers worldwide. Highly effective for detailed documentation of painting and paper objects before and after treatments.
18	**Portable sundial,** British Museum, UK: ∅ 110mm. Bevan 2013.	Options of relighting, zoom, filtering: ideal to make a text legible. RTI cheap and easy to use. Size of the files rather small (<200mb). Files can be shared.	No information. Software: CHI RTIbuilder and Viewer.	Indoor (3 students): academic work.	Recommendations: specific use of specular enhancement + diffuse gain filters. Outcomes: better legibility compared to naked eyes or observation under raking light.
19	**Old manuscripts, 15-20th c.**, Ingels collection, Sweden: 1x1cm. Cosentino 2013.	Application of macro-H-RTI to the study of prints (features on the order of hundreds of μm): limited manipulation of the artefact, once the RTI documentation completed, both realistic and enhanced examination, no data loss due to shadows and specular highlights.	Camera: Nikon D800 (36mpx) with reverse rings (adapter) coupled with a 20mm lens. Light: studio strobes or Nikon SB-600 speedlights triggered remotely. Macro rail and tripod. Reference sphere: ball spheres of point pens labelled as fine (0.5mm<∅<1mm). Aligning of the photographs with Photoshop.	Indoor (1 person).	Recommendations: USB microscope cannot be used since low resolution. Favour studio strobes to speedlights. Smallest reflective ball: GTec-C with 0.25mm but difficult to extract from a pen. Outcomes: identification of the printing technique: woodcuts (lack of sophistication, edge rims, no regularity of width and direction), etching (raised ink), engraving (swelling lines).
20	**Greek and Roman coins**, provenance unknown: ∅	Visual analysis, conservation documentation and monitoring of treatments	Camera: digital SLR + tripod + light source + glossy sphere.	Indoor. RTI data capture and processing is more laborious	Outcomes: with RTI, no data loss caused by shadows and specular highlights. The Dome method provides automation, decreases

	around 2cm. Kotoula 2013.	with a low-cost tool (H-RTI) that limits interaction with artefact and provides high-quality examination.		and time consuming than photography. Although the RTI process is rather simple, familiarising with the technique requires time.	time for capture - processing, and leads to better, more precise results while the highlight method is able to capture data regardless of the size of the objects, without any special instrumentation. A compromise between these two methods is the use of rotation rings or mechanical arms for the automatic moving of light. RTI not only assists identification and dating but also enhances examination (three-dimensionality and geometric complexity), and condition reporting (surface topography of deteriorated material).
21	**Paintings**, mock-up: 1x1m. Manfredi 2014.	Non-invasive and accurate quantitative measurements of morphological changes (0.3mm) in paintings for monitoring purposes.	Camera: Nikon D3100. with an 18mm macro lens + the F-stop was set at f/8 and the exposure time at 0.62s + images are made by 4608×3072pixels, the resolution of the images is 254 dpi and the ground pixel size is 0.1mm. The camera was operated tethered to a PC. Light: semi arch arm with four LEDs (20 Watt) at 15°, 30°, 45° and 60° and rotation of the arm: every 20° + black reflective sphere. Software: CHI RTIbuilder, Python version 2.7.3, Matlab R2010a, ImageJ.	Indoor: 20min. for 48-52 digital images + processing.	Outcomes: quantitative imaging includes the development, standardization, and optimization of imaging acquisition protocols, data analysis, and results interpretation in order to have a validated, reliable, and precise method.
22	**Mural paintings + graffiti,** San Giovanni (4-6th A.C.) in Syracuse, Sicily, I: 0.5m**.** Cosentino 2015.	RTI coupled with IR photography to remove the noise due to the paint and visualise better graffiti.	Camera: Nikon D800 (36mpx, CMOS sensor), modified for full spectrum acquisition (built-in IR filter removed) with a 75mm lens. See above (19) for other details. Black sphere is 3cm (∅).	Indoor.	Outcomes: RTI in the infrared range can perform an even better documentation: some pigments (red ochre) become transparent: photos not disturbed by the paint which has randomly detached from the mural.

REFERENCES

General information / applications / case studies:

- Duffy S.M. (ed.), Multi-light Imaging for Heritage Applications, English Heritage, 2013, http://www.english-heritage.org.uk/publications/multi-light-imaging-heritage-applications/Multi-light_Imaging_FINAL_low-res.pdf. Accessed 11.02.2015.

Papers / Case studies:

- Bevan G. et al., Reflectance transformation imaging of a « Byzantine » portable sundial, Zeitschrift für Papyrologie und Epigraphik 187, 2013, 221–229, http://awmc.unc.edu/wordpress/wp-content/uploads/2013/09/ZPE-187-bevan-lehoux-talbert.pdf. Accessed 13.02.2015.
- Cosentino A., Macro Photography for Reflectance Transformation Imaging: A Practical Guide to the Highlights Method, 1, e-conservation journal, 2013, 71-85, http://www.e-conservation.org/issue-1/20-macro-photography-for-reflectance-transformation-imaging. Accessed 17.02.2015.
- Cosentino A. et al., Innovative imaging techniques for examination and documentation of mural paintings and historical graffiti in the catacombs of San Giovanni, Syracuse, International Journal of Conservation Science, 6, 1, 2015, 23-34, http://www.ijcs.uaic.ro/public/IJCS-15-03_Cosentino.pdf. Accessed 11.03.2015.
- Dellepiane M. et al., High Quality PTM Acquisition: Reflection Transformation Imaging for Large Objects, The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST(2006), 2006, 1-8, http://vcg.isti.cnr.it/Publications/2006/DCCS06/Dellepiane_et_al_High_quality_PTM.pdf. Accessed 17.02.2015.
- Duffy S.M. Polynomial texture mapping at Roughting Linn Rock Art site, International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVIII, Part 5, Commission V Symposium, Newcastle upon Tyne, UK. 2010, 213-217, http://www.isprs.org/proceedings/XXXVIII/part5/papers/159.pdf. Accessed 11.02.2015.
- Gabov A. and Bevan G., Recording the Weathering of Outdoor Stone Monuments Using Reflectance Transformation Imaging (RTI): The Case of the Guild of All Arts (Scarborough, Ontario), *J.ACCR*, 36, 2011, 3-14, https://artcosnervationcsmodotcom.files.wordpress.com/2013/02/vol36_doc1.pdf. Accessed 11.02.2015.
- Kotoula E. and Kyranoudi M., Study of ancient Greek and Roman coins using reflectance transformation imaging, e-conservation, 25, 2013, 75-88, https://www.academia.edu/3515894/Study_of_Ancient_Greek_and_Roman_coins_using_Reflectance_Transformation_Imaging. Accessed 17.02.2015.
- MacDonald L.W., Visualising an Egyptian Artefact in 3D: Comparing RTI with Laser Scanning, EVA 2011, 2011, 155-162, http://ewic.bcs.org/upload/pdf/ewic_ev11_s8paper4.pdf. Accessed 17.02.2015.
- Manfredi M. et al., A New Quantitative Method for the Non-Invasive Documentation of Morphological Damage in Paintings Using RTI Surface Normals, *Sensors* 2014, *14*, 12271-12284, www.mdpi.com/1424-8220/14/7/12271/pdf. Accessed 13.02.2015.
- Manrique Tamayo S.N. et al., Applications of reflectance transformation imaging for documentation and surface analysis in conservation, International Journal of Conservation Science, 4, Special Issue, 2013, 535-548, http://www.ijcs.uaic.ro/public/IJCS-SI-Manrique.pdf. Accessed 12.02.2015.
- Mudge M. et al., Reflection Transformation Imaging and Virtual Representations of Coins from the Hospice of the Grand St. Bernard, The 6th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2005), 2005, 1-11, http://culturalheritageimaging.org/What_We_Do/Publications/vast2005/VAST2005_final.pdf. Accessed 11.02.2015.
- Mudge M. et al., New Reflection Transformation Imaging Methods for Rock Art and Multiple-Viewpoint Display, The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2006), 2006, 1-8, http://culturalheritageimaging.org/What_We_Do/Publications/vast2006/VAST2006_final.pdf. Accessed 11.02.2015.
- Padfield J. et al., Polynomial texture mapping: a new tool for examining the surface of paintings, ICOM-CC preprints, the Hague, 1, 2005, 1, 504-510.
- Payne E.M., Imaging Techniques in Conservation, Journal of Conservation and Museum Studies 10(2) 2012, 17-29, http://dx.doi.org/10.5334/jcms.1021201. Accessed 13.02.2015.
- Piquette K., Reflectance Transformation Imaging (RTI) and Ancient Egyptian Material Culture, Damqatum – The Cehao Newsletter, 7, 2011, 16-20, http://bibliotecadigital.uca.edu.ar/repositorio/revistas/ancient-egyptian-material-culture-piquette.pdf. Accessed 17.02.2015.
- Zanyi E. et al., Lighting and byzantine glass tesserae, EVA London Conference ~ 11–13 July 2007, 2007, 22.1-22.8, http://culturalheritageimaging.org/What_We_Do/Publications/eva2007/EVA_2007.pdf. Accessed 11.02.2015.
- Rabinowitz A. et al., Grass-roots Imaging: A Case-study in Sustainable Heritage Documentation at Chersonesos, Ukraine, CAA2009, Williamsburg, Virginia, USA. March 22--26, 2009, http://culturalheritageimaging.org/What_We_Do/Publications/caa2009/caa_2009_grassroots_paper.pdf. Accessed 11.02.2015.

PowerPoint presentations:

- Evaluating RTI for Enhanced Visualisation of Artefact Surfaces, Piquette: http://cceh.uni-koeln.de/projekte/zimmer/rti/Piquette_RTI.pdf. Accessed 12.02.2015.
- Developing a Reflectance Transformation Imaging (RTI) System for Inscription Documentation in Museum Collections and the Field, Piquette_2011: http://www.digitalclassicist.org/wip/wip2011-01kp.pdf. Accessed 12.02.2015.
- Multi-light recording, interactive HD imaging executable by any researcher, Hameeuw_2014: https://www.arts.kuleuven.be/digitalhumanities/documenten/multi-light-recording-interactive-hd-imaging.pdf. Accessed 1.02.2015.
- Reflectance Transformation Imaging (practical use of CHI RTI softwares), McConnaghy_2014 : http://www.microscopy-uk.org.uk/mag/artnov14macro/Shaun_McConnaghy_RTI.pdf. Accessed 12.02.2015.

Online movies / Experience / applications:

General

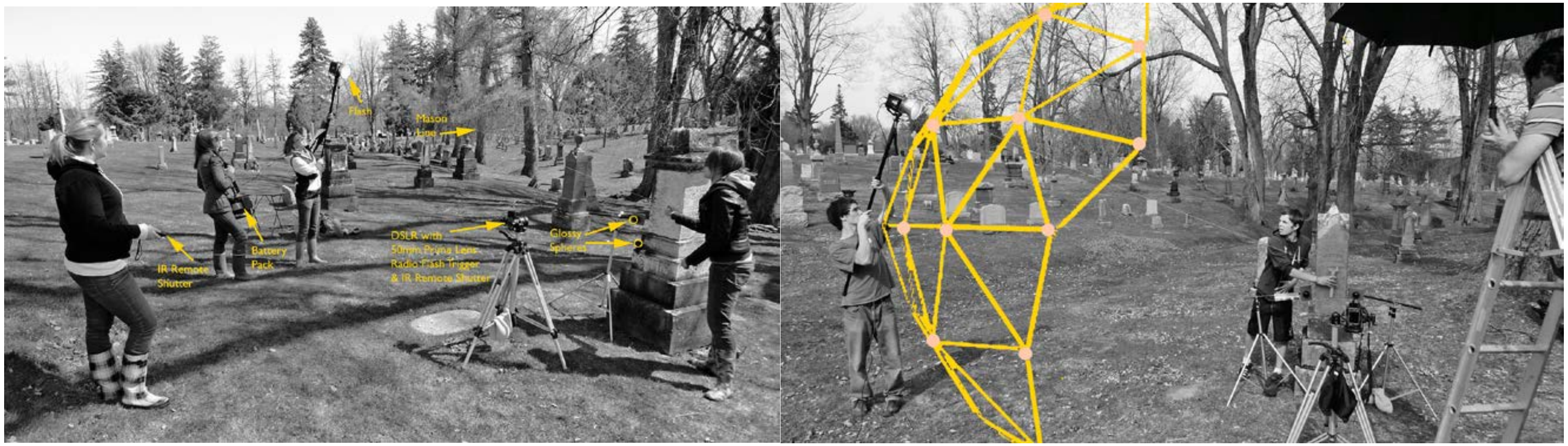
- Performing Reflectance Transformation Imaging, CHI: https://www.youtube.com/watch?v=zddxcSayxcg. Accessed 12.02.2015.
- Reflectance Transformation Imaging (RTI) and Art Conservation (part 1) : https://www.youtube.com/watch?v=FXvnIWGTo5Y. Accessed 12.02.2015.
- Reflectance Transformation Imaging (RTI) and Art Conservation (part 2) : https://www.youtube.com/watch?v=qR_5WkTC638. Accessed 12.02.2015.
- Reflectance Transformation Imaging (RTI) and Art Conservation (part 3) : https://www.youtube.com/watch?v=1iHzUDlpGns. Accessed 12.02.2015.

Application of RTIViewer

- RTI example: Japanese woodblock prints: https://www.youtube.com/watch?v=QGYjTjkJXJ0. Accessed 12.02.2015.
- RTI example: marble stele: https://www.youtube.com/watch?v=gvc6NVYxWuE. Accessed 12.02.2015.
- RTI example: illuminated manuscript: https://www.youtube.com/watch?v=mZMWT09-HyU. Accessed 12.02.2015.
- RTI example: papyrus fragment: https://www.youtube.com/watch?v=F--0gREMbag. Accessed 12.02.2015.
- RTI Example: Rock art: https://www.youtube.com/watch?v=aRBmUW1l9V0. Accessed 12.02.2015.

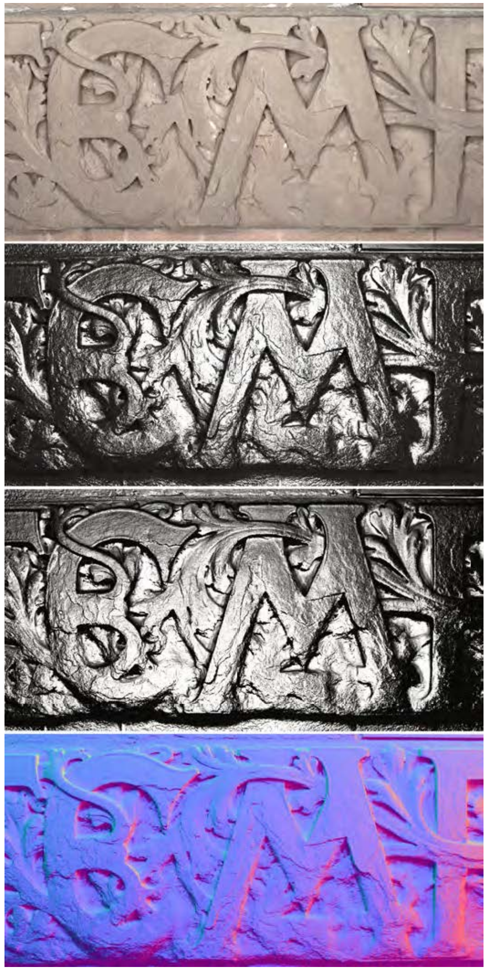
ILLUSTRATIONS OF EXPERIMENTAL SETUPS

Reflectance Transformation Imaging (RTI) and Ancient Egyptian Material Culture, Damqatum: The CEHAO newsletter, 7, 2011, © Hembo Pagi; http://www.english-heritage.org.uk/publications/multi-light-imaging-heritage-applications/Multi-light_Imaging_FINAL_low-res.pdf. Accessed 12.02.2015.



RTI field set-up in action in the Cataraqui Cemetery, Kingston, Ontario. RTI equipment labelled and ideal light distribution superimposed. Gabov et al., JCAC, 2011.

EXAMPLES OF APPLICATIONS



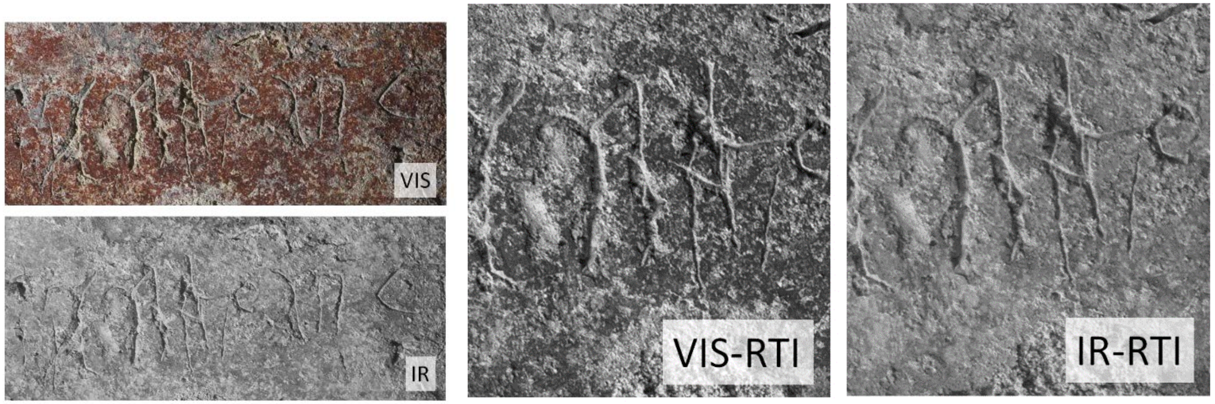
a

b

c

d

Close-up of the Temple Building inscription, in natural light (a), specular Enhancement of the H-RTI (b), specular Enhancement of the H-RTI using a different light position than in b (c) and surface Normal Visualization of the RTI (d). Gabov, JCAC, 2011.



a b

Graffitis on wall paintings of the Catacombs of San Giovanni, Syracuse, Sicily, I. Two images taken with the same raking light direction: red ochre transparent in IR and incisions revealed without the noise from the paint losse (a) and IR-RTI versus VIS-RTI with the specular enhancement applied (b), Cosentino, IJCS, 6, 1, 2015, 23-34.

a b c d

Copper alloy coin, SALUSAVGG/ Salus standing right, holding out a patera in her left hand to feed a snake held in her right hand (∅ 22mm): digital image before (a) with RTI visualization (b) and after treatment (c) with RTI visualization (d), Kotoula, e-conservation, 25, 2013, 75-88.

Task st4.2: Development of guidelines

Existing guidelines can be found in the document: Multi-light Imaging for Heritage Applications, S.M. Duffy, English Heritage, 2013. They are summarised below:

Advantages:
- Non-invasive, horizontal or vertical positions, 2-3 persons max. to operate, adapted to VIS, IR and UV examination and to artefacts monitoring.

Limitations:
- “Artisanal” recording technique (care in field setup and knowledge on technical photography). Qualitative.

Size of the object	**Recording location**	**Environment**	**Light / shadow**	**Camera**	**Targets**	**Power source**	**Additional equipment / Conditions**	**Data storage / size of files**	**Cost**
From micro-scopic objects to 2m max.	Space with stable flooring (no wood) + large enough for light source to be separated by at least x3-4 the diameter of object	Indoors: prevent ambient light (artificial and day light). If daylight needed or outdoors: use neutral density filters + wind: fix the tripod	Continuous or flash on extended arm. If flash: remote control by camera / Minimise shadowing caused by tripods, targets, the object	Digital SLR (>8mpx) + photograph in RAW + manual mode + remote control + tightly fixed + normal lens recommended	Reflective, unmarked and spherical + black or red + should be 2 + size depends on the object + should take 200pixels of the image + in the shot but to crop out.	Remote recording require a battery-operated light source	Greyscale + colour checker + scale ruler + cable ties + “Blu Tack” + spirit-level to align camera / Shots at 3 angles (15 above the horizon to 65°) and 8 positions around the clock: 24 shots min. + black/white/grey background behind object if portable.	Card large enough for a complete set of RAW photographs (4GB) / PTM 200Kko	Kit: 500£ (camera + reflective targets + light source + tripod + strings – Software free

Camera adjustments:

- Better to keep aperture set between f/5.6 and 11.
- ISO setting as low as possible: 100 – 200 is optimal
- Short exposure times: shutter speed of 1/60 or faster
- Check histogram curve: no whites are blown out and no shadows are too dark

Conditions of use summarized:

- Place the object on a stable surface (if portable).
- Mount the camera over the selected capture area.
- Position the reflective targets in the shot far enough away from the object so that they can be cropped during post processing.
- Set the camera to photograph in RAW, focus it on the object and then set the camera and the lens to manual.

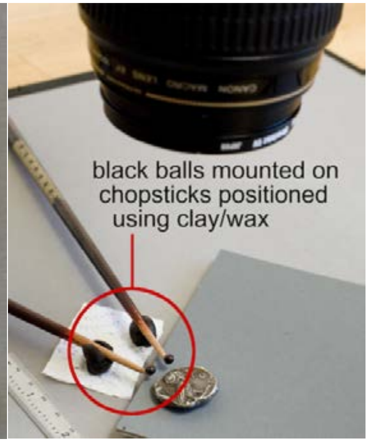
- If it has not been incorporated into the photo set-up, take one image with a greyscale card.

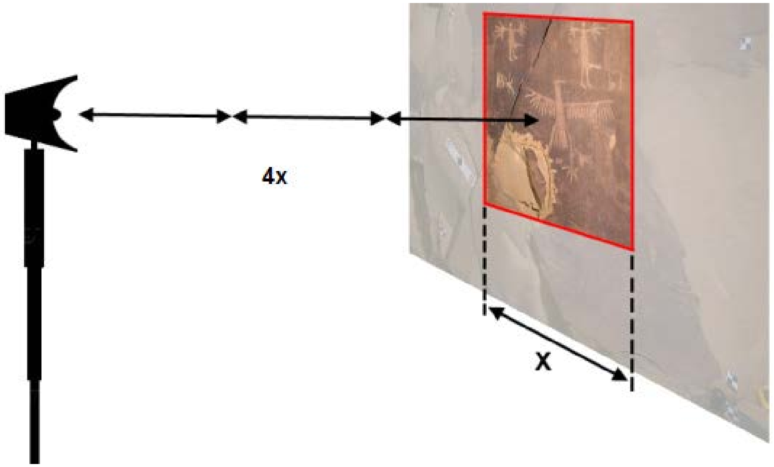
<u>Fieldwork</u>:

- Ensure that the proper equipment has been selected and checked before any field work.

Illustrations of recommended setups

(from Reflectance Transformation Imaging: Guide to Highlight Image Capture, v1.1 © 2010 Cultural Heritage Imaging. All rights reserved).





http://www.c-h-i.org/learn/media/RTI_Hlt_Capture_Guide.pdf. Accessed 12.02.2015.

REFERENCES

Guidelines / general information:

- CHI: Reflectance Transformation Imaging: Guide to Highlight Image Capture v 1.1., Cultural Heritage Imaging, 2010. http://www.c-h-i.org/learn/media/RTI_Hlt_Capture_Guide.pdf. Accessed 11.02.2015.
- Cosentino A., Macro Photography for Reflectance Transformation Imaging: A Practical Guide to the Highlights Method, 1, e-conservation journal, 2013, 71-85, http://www.e-conservation.org/issue-1/20-macro-photography-for-reflectance-transformation-imaging. Accessed 17.02.2015.
- Duffy S.M. (ed.), Multi-light Imaging for Heritage Applications, English Heritage, 2013, http://www.english-heritage.org.uk/publications/multi-light-imaging-heritage-applications/Multi-light_Imaging_FINAL_low-res.pdf. Accessed 11.02.2015.

Standard conservation procedures: Reflectance Transformation Imaging Systems for Ancient Documentary Artefacts (RTI-SAD) project:
- Earl G. et al., Reflectance Transformation Imaging Systems for Ancient Documentary Artefacts, In: Dunn, S, Bowen, J and Ng, K. (eds.) EVA London 2011. Electronic Visualisation and the Arts. Proceedings of a conference held in London, 6–8 July 2011. BCS, The Chartered Institute for IT, 147–54, http://ewic.bcs.org/upload/pdf/ewic_ev11_s8paper3.pdf. Accessed 13.02.2015.

Softwares to download:

RTIBuilder: http://culturalheritageimaging.org/What_We_Offer/Downloads/Process/index.html
RTIViewer: http://culturalheritageimaging.org/What_We_Offer/Downloads/View/index.html
Hewlett Packard, Polynomial texture mapping (PTM): http://www.hpl.hp.com/research/ptm/downloads/download.html

PowerPoint presentations:

- Evaluating RTI, Piquette: http://cceh.uni-koeln.de/projekte/zimmer/rti/Piquette_RTI.pdf. Accessed 12.02.2015.
- Developing a Reflectance Transformation Imaging (RTI) System for Inscription Documentation in Museum Collections and the Field, Piquette_2011: http://www.digitalclassicist.org/wip/wip2011-01kp.pdf. Accessed 12.02.2015.
- Multi-light recording, interactive HD imaging executable by any researcher, Hameeuw_2014: https://www.arts.kuleuven.be/digitalhumanities/documenten/multi-light-recording-interactive-hd-imaging.pdf. Accessed 1.02.2015.
- Reflectance Transformation Imaging (practical use of CHI RTI softwares), McConnaghy_2014: http://www.microscopy-uk.org.uk/mag/artnov14macro/Shaun_McConnaghy_RTI.pdf. Accessed 12.02.2015.

Online movies / Experience / applications / RTI tips and tricks:

- Cosentino A., Cultural Heritage Science Open Source, RTI Reflectance Transformation Imaging: tips and tricks, http://chsopensource.org/category/rti/, Accessed 12.02.2015.

Teams currently active in H-RTI

- Cultural Heritage Imaging, USA

http://culturalheritageimaging.org/Technologies/RTI/

- University of Southampton, UK, Archaeological Computing Research Group (Graeme Earl, Kirk Martinez, Hembo Pagi)

http://acrg.soton.ac.uk/

- University of Oxford, UK, Centre for the Study of Ancient Documents (Alan Bowman, Charles Crowther, Leif Isaksen and Jacob Dahl)

http://www.csad.ox.ac.uk/

- Warwick University, UK, Visualisation group (Alan Chalmers)

http://www2.warwick.ac.uk/fac/sci/wmg/research/visualisation/research/

- University College London, UK, Civil, Environmental and Geomatic Engineering, 3DIMPact: 3D Imaging, Metrology, Photogrammetry Applied Coordinate Technologies (Lindsay MacDonald)

http://www.cege.ucl.ac.uk/Research/Pages/3DIMPact.aspx

- University of Leuven, BE, Ancient New Eastern Studies (Hendrik Hameeuw)

- University of Leuven, BE, Centre for the Study of Medieval Art (Prof J. van der Stock)

http://www.illuminare.be/rich_project (RICH project: Reflectance imaging for Cultural Heritage)

- University of Cologne, DE, Cologne Centre for e-Humanities (Kathryn Piquette)

http://www.cceh.uni-koeln.de/

- Smithsonian Institute, USA, Museum Conservation Institute (Melvin Wachowiak)

http://www.si.edu/MCIImagingStudio/RTI and http://www.csad.ox.ac.uk/ (Squeeze Imaging project)

- University of Yale, USA, Institute for the Conservation of Cultural Heritage (Chelsea Graham)

http://ipch.yale.edu/imaging-reflectance-transformation-imaging-system-rti

- Cultural Heritage Science Open Source, Antonio Cosentino, I

http://chsopensource.org/category/rti/

- Conservation of Sculptures, Monuments and Objects (CSMO), Canada

https://artcosnervationcsmodotcom.wordpress.com/category/rti/